CONSTITUTIVE MODELLING OF FIBRE REINFORCED CONCRETE AND SHOTCRETE

VOLUME 2

By

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the requirements for the degree of
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ORIGINALITY

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Signed:

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Tran Nguyen Gia Vinh

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10/7/2003

PREFACE

This thesis includes two volumes. Volume 1 is the body of the research. Volume 2 contains the research reports, experimental results, and research papers.

CONTENT

1. SOFTWARES

1.1. Introduction

MCSRDP2, MCSTV and BEAMYLT were developed utilising using the Lahey Fortran F77L programming language with the main objective to derive the non-linear post-cracking load-deflection and moment-crack rotation relationships using yield line analysis incorporating MCS analysis. The first program is used to analyse the RD panel. The second similar to the first one is used to analyse the RD panel taking into account the effect of thickness. The last program is used to analyse the beam using the results of RD panels.

The program was written as a main file MCSRDP2.for, MCSTV.for and BEAMYLT.for which are listed in next section. The main files were translated into the executable files (For example: MCSRDP2.exe) which are compatible on IBM processors. The size of the executable file is about 442 Kbytes. Using P2–350HZ computer, it takes about 8 to 10 minutes for 10,000 iterations in MCS analysis. The faster computer can reduce the time to run the simulation. The output file is in the extension of .for, which can be processed in Excel Spreadsheet program.

1.2. Source Code

In this section, the source codes of the programs were listed below. They were written respectively in Fortran languages. The structures of the programs were shown in the Volume 1.

1.2.1. MCSRDP2.for

```
C  Monte Carlo analysis for crack modelling in fibre reinforced
C  shotcrete round panels using yield line analysis
C  Author:    Vinh Tran
C  Commenced: 1st June 2000

C      MAIN PROGRAM

       Program RDP2

       Data k,j,im,rm / 5701,3612,566927,566927.0/

       Integer Niter
       Integer Iter
       Common /Iteration/ Niter, Iter

       Real IniVar1,IniVar2,IniVar3
       Common /RandomData/ IniVar1,IniVar2,IniVar3

C      ----- Declare of Beam Variables -------

       Real BeamWidth
       Real BeamLength
       Real BeamDepth

       Integer NumBeamPoints
       Real BeamRotation(1001)
       Real BeamMoment(1001)

       Common /BeamData/ BeamWidth, BeamLength, BeamDepth
       Common /BeamData/ NumBeamPoints
       Common /BeamData/ BeamRotation, BeamMoment

C      ------Declare of Slab Variables ------
```

```
      Real SlabDiameter
      Real SlabDepth

      Common /SlabData/ SlabDiameter, SlabDepth

C     ------ Declare of Yield Line Data ------

      Integer NumYieldLines
      Real Angle(3,10000)
      Real EndX(3)
      Real EndY(3)
      Real Aphad(3,10000)

      Common /LineData/ NumYieldLines, Angle, Aphad
      Common /LineData/ EndX, EndY

C     ------ Output Data ------

      Integer NumSlabPoints

      Real SlabDeflection(1001)
      Real SlabCapacity(1001)
      Real SlabDeflection2(10000)
      Real SlabCapacity2(10000)
      Real PeakLoad(10000)

      Common /OutputData/ NumSlabPoints,PeakLoad
      Common /OutputData/ SlabDeflection, SlabCapacity
      Common /OutputData/ SlabDeflection2,SlabCapacity2

C     ------ Other Variables --------

      Integer Choice

      Common /OtherData/Choice

C     -------------------------------------------------
      Character*(1) Response

      Call DisplayWelcome
```

```
      Print *, " Let start the input (y/n) ?  "
      Read *, Response

      If ((Response .eq. "y") .or. (Response .eq. "Y")) then
      Print *," Input Iteration Number = "
      Read*,Niter

C     Input the initial random number in (0,1)

      Print*," Please enter the random numbers in range (0,1)"
      Print*," Initial Variable 1 = "
      Read*,IniVar1
      Print*," Initial Variable 2 = "
      Read*,IniVar2
      Print*," Initial Variable 3 = "
      Read*,IniVar3

      Call GetBeamInfo
      Call GetSlabInfo
      Call GetYieldLineInfo

C     ----- Start the Iteration Run -----

      Do 1 Iter=1,Niter

      Ix1=int(IniVar1*rm)
      Irand1=mod(j*ix1+k,im)
      IniVar1=(real(irand1)+0.5)/rm

      Ix2=int(IniVar2*rm)
      Irand2=mod(j*ix2+k,im)
      IniVar2=(real(irand2)+0.5)/rm

      Ix3=int(IniVar3*rm)
      Irand3=mod(j*ix3+k,im)
      IniVar3=(real(irand3)+0.5)/rm

      Call CalcSlabCurve
      Call CalcAngle
```

```
 1   Continue

     Call SaveSlabCurve

     End if
     End

C    --------------------------
     Subroutine DisplayWelcome

     Call system("cls")

     Print *, "    ÉÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ»"
     Print *, "    º     Round Determinate Panel 1.0     º"
     Print *, "    º   Copyright (C) 2000 by VINH TRAN    º"
     Print *, "    ÈÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ¼"
     Print *, " "
     Print *, " "
     Print *, " "
     Print *, " "
     Print *, " "
     Print *, " "
     Print *, " "
     Print *, " "
     Print *, " "
     Print *, " "
     Print *, " "
     End

C    --------------------------------------------------------
     Subroutine GetBeamInfo

C    ------ Other Data ------

     Integer Choice

     Common /OtherData/Choice

     Choice = 0
```

```
      Do while ((Choice .ne. 1) .and. (Choice .ne. 2)
     &        .and. (Choice .ne. 3) .and. (Choice .ne. 4))

      Call system( "cls" )

      Print*,"BEAM TEST RESULTS"
      Print*,"_________________"
      Print*," "
      Print*," "
      Print*,"  1. Beam Test Results in Set 1"
      Print*,"  2. Beam Test Results in Set 2"
      Print*,"  3. Beam Test Results in Set 3"
      Print*,"  4. Beam Test Results in Set 4"

      Print*," "
      Print*,"  Enter The Choice =  "
      Read *, Choice

      End do

      Call GetBeamDimensions

      End

C     ------------------------------------------------------
      Subroutine OpenBeamInfo

      Integer n
      Character*(50) FileName

C     ----- Declare of Beam Variables ------

      Real BeamWidth
      Real BeamLength
      Real BeamDepth
      Integer NumBeamPoints
      Real BeamRotation(1001)
      Real BeamMoment(1001)
```

```
      Common /BeamData/ BeamWidth, BeamLength, BeamDepth
      Common /BeamData/ NumBeamPoints
      Common /BeamData/ BeamRotation, BeamMoment

C     ----------------------------

      Call GetFileName(FileName)

      Open(Unit=1, File=FileName, Status='OLD' )

      Read(Unit=1,Fmt=110) BeamLength, BeamWidth, BeamDepth
 110  Format(F10.4, T12, F10.4, T24, F10.4 )
      Read(Unit=1, Fmt=120) NumBeamPoints
 120  Format(I10)

      n = 1
      Do while (n.le.NumBeamPoints)
      Read(Unit=1, Fmt=130) BeamRotation(n), BeamMoment(n)
 130  Format(F10.6, T12, F10.4)
      n = n + 1
      End Do

      EndFile(Unit=1)
      Close(Unit=1)

      End

C     ------------------------------------------------------
      Subroutine GetBeamDimensions

      Logical Finished

C     ----- Declare of Beam Variables -----

      Real BeamWidth
      Real BeamLength
      Real BeamDepth
      Integer NumBeamPoints
      Real BeamRotation(1001)
      Real BeamMoment(1001)
```

```
      Common /BeamData/ BeamWidth, BeamLength, BeamDepth
      Common /BeamData/ NumBeamPoints
      Common /BeamData/ BeamRotation, BeamMoment

C     -------------------------------------------------------

      Call system( "cls" )

      Print *, "BEAM DIMENSIONS"
      Print *, "_______________"
      Print *, " "
      Print *, " "
      Print *, "Enter Beam Dimensions (mm)  "

      Finished = .false.

      Do while (.not.finished)
      Print*,"Length =  "
      Read*,BeamLength

      If (BeamLength.LE.0) then
      Print *, "ERROR: Length must be greater than 0."
      Else
            Finished = .true.
      End if
      End Do

      Finished=.false.

      Do while (.not.finished)
      Print*,"Width =  "
      Read*,BeamWidth

      If (BeamWidth.LE.0) then
      Print*,"ERROR: Width must be greater than 0."
      Else
            Finished=.true.
      End If
      End Do
```

```
      Finished=.false.

      Do while (.not.finished)
      Print*,"Depth =  "
      Read*,BeamDepth

      If (BeamDepth.LE.0) then
      Print*,"ERROR: Depth must be greater than 0."
      Else
            Finished=.true.
      End if
      End Do

      Print*," "

      End

C     -------------------------------------------------------
      Subroutine GetBeamMeasurements

      Logical Finished
      Integer n

C     ----- Declare of Beam Variables ------

      Real BeamWidth
      Real BeamLength
      Real BeamDepth
      Integer NumBeamPoints
      Real BeamRotation(1001)
      Real BeamMoment(1001)

      Common /BeamData/ BeamWidth, BeamLength, BeamDepth
      Common /BeamData/ NumBeamPoints
      Common /BeamData/ BeamRotation, BeamMoment

C     -------------------------------------------------------

      Call system( "cls" )
```

```
Print*,"MOMENT/ROTATION DATA POINTS"
Print*,"_______________________________"
Print*," "
Print*,"The results of the beam test must be input here"
Print*,"For each rotation data point, the moment capacity "
Print*,"have to be entered "
Print*," "
Print*,"Please enter the number of data points "

Finished=.false.
Do while (.not.finished)
Print*,"Number of data points =  "
Read *, NumBeamPoints

If ((NumBeamPoints.LE.0) .or. (NumBeamPoints > 100)) then
Print*,"ERROR: No. of points must be between 1 & 100."
Else
        Finished = .true.
End If
End Do

Print*," "

n = 1
Do while (n.LE.NumBeamPoints)
Print*,"Point ", n, ": "
Print*,"Rotation (in radians) = "
Read*,BeamRotation(n)
Print*,"Moment (in Nmm) =  "
Read*,BeamMoment(n)
Print*," "
n = n + 1
End Do

End

C    -------------------------------------------------------
Subroutine SaveBeamInfo
```

```
      Character*(1)  Selection
      Character*(50) FileName

      Call system( "cls" )

      Print*,"SAVE BEAM INFORMATION"
      Print*,"______________________"
      Print*," "
      Print*,"Do you want to save the beam information that "
      Print*,"you have just entered to a file (for use with "
      Print*,"other beams)?   (y/n)  "

      Read*,Selection

      If ((Selection.eq."y").or.(Selection.eq."Y")) then
      Call GetFileName( FileName )

      Print*," "
      Print*,"Saving to ", FileName, "..."

      Call OutputBeamInfo(FileName)

      Print*," "
      Print*,"Done. "

      End if

      End

C     ------------------------------------------------------
      Subroutine GetFileName(FileName)

C     ----- Parameters -----

      Character*(50) FileName

      Print*," "
      Print*,"Please enter the file name =  "
      Read*,FileName
```

```
      End

C     --------------------------------------------------------
      Subroutine OutputBeamInfo(FileName)

C     ----- Parameters -----

      Character*(50) FileName
      Integer n

C     ----- Declare of Beam Variables ------

      Real BeamWidth
      Real BeamLength
      Real BeamDepth
      Integer NumBeamPoints
      Real BeamRotation(1001)
      Real BeamMoment(1001)

      Common /BeamData/ BeamWidth, BeamLength, BeamDepth
      Common /BeamData/ NumBeamPoints
      Common /BeamData/ BeamRotation, BeamMoment

C     --------------------------------------------------------

      Open(Unit=1, File=FileName, Status='NEW')

      Write(Unit=1, Fmt=10) BeamLength, BeamWidth, BeamDepth
 10   Format(F10.4, T12, F10.4, T24, F10.4 )

      Write(Unit=1, Fmt=20) NumBeamPoints
 20   Format(I10)

      n = 1
      Do while ( n .le. NumBeamPoints )
      Write(Unit=1, Fmt=30) BeamRotation(n), BeamMoment(n)
 30   Format(F10.6, T12, F10.4)
      n = n + 1
      End Do
```

```
      EndFile(Unit=1)
      Close(Unit=1)

      End

C     -------------------------------------------------------
      Subroutine GetSlabInfo

      Call system( "CLS" )

      Print*,"SLAB INFORMATION"
      Print*,"________________"
      Print*," "
      Print*," "
      Print*," "

      Call GetSlabDimensions

      End

C     -------------------------------------------------------
      Subroutine GetSlabDimensions

C     ----- Declare of Slab Variables -----

      Real SlabDiameter
      Real SlabDepth

      Common /SlabData/ SlabDiameter, SlabDepth

      Logical Finished

      Print*,"Enter RDP Dimensions (mm)  "

      Finished=.false.
      Do while (.not.finished)
      Print*,"Diameter =  "
      Read*,SlabDiameter

      If (SlabDiameter.LE.0) then
```

```
      Print*,"ERROR: Diameter must be greater than 0."
      Else
      Finished=.true.
      End If
      End Do

      Finished=.false.
      Do while (.not.finished)
      Print*,"Depth =  "
      Read *,SlabDepth
      If (SlabDepth.LE.0) then
      Print*,"ERROR: Depth must be greater than 0."
      Else
      Finished=.true.
      End If
      End Do

      Print*," "

      End

C     -------------------------------------------------------
      Subroutine GetYieldLineInfo

      Real PI,s1,s2,s3,c1p,c2p,c3p,c1m,c2m,c3m,sq3,A,B,C
      Real c13,c21,c32,s13,s21,s32,a2,a3,b2,b3,Delta

      Integer Niter
      Integer Iter
      Common /Iteration/ Niter, Iter

      Real IniVar1,IniVar2,IniVar3
      Common /RandomData/ IniVar1,IniVar2,IniVar3

C     ----- Declare of Yield Line Data ------

      Integer NumYieldLines
      Real Angle(3,10000)
      Real EndX(3)
      Real EndY(3)
```

```
      Real Aphad(3,10000)

      Common /LineData/ NumYieldLines, Angle, Aphad
      Common /LineData/ EndX, EndY

C     ------------------------------------------------

      NumYieldLines=3

C     ----- Convert all angles into radians -----

      PI=3.14159265358979
      Angle(1,1)=(PI/180)*13.037712*(-alog(IniVar1))**(1/1.108481)
      Angle(2,1)=(PI/180)*13.037712*(-alog(IniVar2))**(1/1.108481)
      Angle(3,1)=(PI/180)*13.037712*(-alog(IniVar3))**(1/1.108481)

C     ----- Calculate corner angles for the first iteration -----

      s1=sin(Angle(1,1))
      s2=sin(Angle(2,1))
      s3=sin(Angle(3,1))
      c1p=cos(Angle(1,1)+PI/6)
      c2p=cos(Angle(2,1)+PI/6)
      c3p=cos(Angle(3,1)+PI/6)
      c1m=cos(Angle(1,1)-PI/6)
      c2m=cos(Angle(2,1)-PI/6)
      c3m=cos(Angle(3,1)-PI/6)
      c13=cos(PI/3-Angle(1,1)+Angle(3,1))
      c21=cos(PI/3-Angle(2,1)+Angle(1,1))
      c32=cos(PI/3-Angle(3,1)+Angle(2,1))
      s13=sin(PI/3-Angle(1,1)+Angle(3,1))
      s21=sin(PI/3-Angle(2,1)+Angle(1,1))
      s32=sin(PI/3-Angle(3,1)+Angle(2,1))
      sq3=sqrt(3)

      a2=c2p*(sq3*s3*c32+c3m*s32)-sq3*s2*(c3m*c32-sq3*s3*s32)
      a3=c2m*(c3m*c32-sq3*s3*s32)
      b2=c2p*c32*c21+s32*sq3*s2*c21+s32*c2m*s21
      b3=-s21*(c2p*c32+sq3*s32*s2)+s32*c2m*c21
      A=(a3*s21-a2*c21)*(-sq3*s1*s13+c1m*c13)
```

```
&   +b2*c3p*(sq3*s1*c13+c1m*s13)
    B=-c1p*s13*(a3*s21-a2*c21)+(a2*s21+a3*c21)*(c1m*c13-sq3*s1*s13)
&   +c3p*(b2*c1p*c13+b3*(sq3*s1*c13+c1m*s13))
    C=b3*c1p*c3p*c13-(a2*s21+a3*c21)*c1p*s13
    Delta=abs(B*B-4*A*C)
    If(A.eq.0) Aphad(1,1)=atan(-B/C)
    If(A.eq.0.and.C.eq.0) Aphad(1,1)=0
    If(A.ne.0) Aphad(1,1)=atan((-B+sqrt(Delta))/(2*A))

    a2=c3p*(sq3*s1*c13+c1m*s13)-sq3*s3*(c1m*c13-sq3*s1*s13)
    a3=c3m*(c1m*c13-sq3*s1*s13)
    b2=c3p*c13*c32+s13*sq3*s3*c32+s13*c3m*s32
    b3=-s32*(c3p*c13+sq3*s13*s3)+s13*c3m*c32
    A=(a3*s32-a2*c32)*(-sq3*s2*s21+c2m*c21)
&   +b2*c1p*(sq3*s2*c21+c2m*s21)
    B=-c2p*s21*(a3*s32-a2*c32)+(a2*s32+a3*c32)*(c2m*c21-sq3*s2*s21)
&   +c1p*(b2*c2p*c21+b3*(sq3*s2*c21+c2m*s21))
    C=b3*c1p*c2p*c21-(a2*s32+a3*c32)*c2p*s21
    Delta=abs(B*B-4*A*C)
    If(A.eq.0) Aphad(2,1)=atan(-B/C)
    If(A.eq.0.and.C.eq.0) Aphad(2,1)=0
    If(A.ne.0) Aphad(2,1)=atan((-B+sqrt(Delta))/(2*A))

    a2=c1p*(sq3*s2*c21+c2m*s21)-sq3*s1*(c2m*c21-sq3*s2*s21)
    a3=c1m*(c2m*c21-sq3*s2*s21)
    b2=c1p*c21*c13+s21*sq3*s1*c13+s21*c1m*s13
    b3=-s13*(c1p*c21+sq3*s21*s1)+s21*c1m*c13
    A=(a3*s13-a2*c13)*(-sq3*s3*s32+c3m*c32)
&   +b2*c2p*(sq3*s3*c32+c3m*s32)
    B=-c3p*s32*(a3*s13-a2*c13)+(a2*s13+a3*c13)*(c3m*c32-sq3*s3*s32)
&   +c2p*(b2*c3p*c32+b3*(sq3*s3*c32+c3m*s32))
    C=b3*c2p*c3p*c32-(a2*s13+a3*c13)*c3p*s32
    Delta=abs(B*B-4*A*C)
    If(A.eq.0) Aphad(3,1)=atan(-B/C)
    If(A.eq.0.and.C.eq.0) Aphad(3,1)=0
    If(A.ne.0) Aphad(3,1)=atan((-B+sqrt(Delta))/(2*A))

    End

C   -----------------------------------------------
```

```
      Subroutine CalcSlabCurve

      Real LookUp
      Integer*4 n
      Real Deflection
      Real MinDeflection
      Real MaxDeflection
      Real DeltaDeflection
      Real IniVar4

      Integer Niter
      Integer Iter
      Common /Iteration/ Niter, Iter

      Real IniVar1,IniVar2,IniVar3
      Common /RandomData/ IniVar1,IniVar2,IniVar3

C     ----- Declare of Yield Line Data -----

      Integer NumYieldLines
      Real Angle(3,10000)
      Real EndX(3)
      Real EndY(3)
      Real Aphad(3,10000)

      Common /LineData/ NumYieldLines, Angle, Aphad
      Common /LineData/ EndX, EndY

C     ----- Output Data -----

      Integer NumSlabPoints

      Real SlabDeflection(1001)
      Real SlabCapacity(1001)
      Real SlabDeflection2(10000)
      Real SlabCapacity2(10000)
      Real PeakLoad(10000)

      Common /OutputData/ NumSlabPoints,PeakLoad
      Common /OutputData/ SlabDeflection, SlabCapacity
```

```
      Common /OutputData/ SlabDeflection2,SlabCapacity2

C     -----------------------------------------------

      Call System("CLS")

      Print*,"THEORETICAL RDP CALCULATIONS"
      Print*," "
      Print*,"ITERATION = ",Iter

      MinDeflection=0.000
      MaxDeflection=40.000
      DeltaDeflection=0.04

C     ----- Calculate the load-deflection curve -----

      n = 1
      Deflection = MinDeflection
      Do while (Deflection.LE.MaxDeflection)
      NumSlabPoints = n
      SlabDeflection(n) = Deflection
      Call CalcCapacity(SlabDeflection(n),SlabCapacity(n),n)
      n = n + 1
      Deflection = Deflection + DeltaDeflection
      End do

      PeakLoad(Iter)=SlabCapacity(1)

C     ----- Pick up a random deflection and interpolate -----
C     ----- the corresponding moment capacity -----

      IniVar4=IniVar3
      Ix4=int(IniVar4*566927.0)
      Irand4=mod(3612*ix4+5701,566927)
      IniVar4=(real(Irand4)+0.5)/566927.0
      IniVar4=40.000*IniVar4
      SlabDeflection2(Iter)=IniVar4
      SlabCapacity2(Iter)= LookUp(IniVar4,NumSlabPoints,
     &                 SlabDeflection,SlabCapacity)
```

```
      End

C     ---------------------------------------------------
      Subroutine CalcCapacity(Deflection,Capacity,NSP)

      Real ex
      Real Deflection
      Real Capacity

C     ----- Variables -----

      Real A,B,C,D,E,F,G,H,I,J,PII
      Real R(12),U(12)
      Real Length
      Integer*4 n
      Real Scale
      Real CrackCapacity

C     ----- Iteration Variables -----

      Integer Niter
      Integer Iter
      Common /Iteration/ Niter, Iter

C     ----- Initial Random Variable -----

      Real IniVar1,IniVar2,IniVar3
      Common /RandomData/ Inivar1,IniVar2,IniVar3

C     ----- Declare of Yield Line Data -----

      Integer NumYieldLines
      Real Angle(3,10000)
      Real EndX(3)
      Real EndY(3)
      Real Aphad(3,10000)

      Common /LineData/ NumYieldLines, Angle, Aphad
      Common /LineData/ EndX, EndY
```

```
C      ----- Beam Data Variables -----

       Real BeamWidth
       Real BeamLength
       Real BeamDepth
       Integer NumBeamPoints
       Real BeamRotation(1001)
       Real BeamMoment(1001)

       Common /BeamData/ BeamWidth, BeamLength, BeamDepth
       Common /BeamData/ NumBeamPoints
       Common /BeamData/ BeamRotation, BeamMoment

C      ----- Declare of Slab Variables -----

       Real SlabDiameter
       Real SlabDepth

       Common /SlabData/ SlabDiameter, SlabDepth

C      ----- Other Data -----

       Integer Choice
       Common /OtherData/Choice

C      -------------------------------------------------

       Capacity = 0
       PII = 3.14159265358979
       Scale = 1.0
       Scale = Scale*(SlabDepth*SlabDepth)
     &      /(BeamDepth*BeamDepth)

       If (NSP.eq.1) then

       Length=SlabDiameter/2

       A = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
     &    cos(PII/3-angle(1,Iter))*
     &    sin(Aphad(1,Iter))
```

```
  B = (0.5*SlabDiameter-25)*sin(PII/3-angle(1,Iter))*
&     sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
  C = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
&     cos(PII/3+angle(1,Iter))*
&     sin(Aphad(1,Iter))
  D = (0.5*SlabDiameter-25)*sin(PII/3+angle(1,Iter))*
&     sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
  R(1) = (A/B) + (C/D)
  A = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
&     cos(PII/3-angle(2,Iter))*
&     sin(Aphad(2,Iter))
  B = (0.5*SlabDiameter-25)*sin(PII/3-angle(2,Iter))*
&     sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
  C = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
&     cos(PII/3+angle(2,Iter))*
&     sin(Aphad(2,Iter))
  D = (0.5*SlabDiameter-25)*sin(PII/3+angle(2,Iter))*
&     sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
  R(2) = (A/B) + (C/D)
  A = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
&     cos(PII/3-angle(3,Iter))*
&     sin(Aphad(3,Iter))
  B = (0.5*SlabDiameter-25)*sin(PII/3-angle(3,Iter))*
&     sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
  C = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
&     cos(PII/3+angle(3,Iter))*
&     sin(Aphad(3,Iter))
  D = (0.5*SlabDiameter-25)*sin(PII/3+angle(3,Iter))*
&     sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
  R(3) = (A/B) + (C/D)

  If (Choice.eq.1) then
  Capacity =1000*Scale*Length*888*(R(1)+R(2)+R(3))/Beamwidth
  End IF

  If (Choice.eq.2) then
  Capacity =1000*Scale*Length*681*(R(1)+R(2)+R(3))/Beamwidth
  End IF

  If (Choice.eq.3) then
```

```
Capacity =1000*Scale*Length*969*(R(1)+R(2)+R(3))/Beamwidth
End IF

If (Choice.eq.4) then
Capacity =1000*Scale*Length*988*(R(1)+R(2)+R(3))/Beamwidth
End IF

End If


If (NSP.gt.1) then

 A = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
&    cos(PII/3-angle(1,Iter))*
&    sin(Aphad(1,Iter))
 B = (0.5*SlabDiameter-25)*sin(PII/3-angle(1,Iter))*
&    sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
 C = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
&    cos(PII/3+angle(1,Iter))*
&    sin(Aphad(1,Iter))
 D = (0.5*SlabDiameter-25)*sin(PII/3+angle(1,Iter))*
&    sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
 R(1) = atan(abs(A/B)*Deflection) + atan(abs(C/D)*Deflection)
 A = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
&    cos(PII/3-angle(2,Iter))*
&    sin(Aphad(2,Iter))
 B = (0.5*SlabDiameter-25)*sin(PII/3-angle(2,Iter))*
&    sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
 C = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
&    cos(PII/3+angle(2,Iter))*
&    sin(Aphad(2,Iter))
 D = (0.5*SlabDiameter-25)*sin(PII/3+angle(2,Iter))*
&    sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
 R(2) = atan(abs(A/B)*Deflection) + atan(abs(C/D)*Deflection)
 A = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
&    cos(PII/3-angle(3,Iter))*
&    sin(Aphad(3,Iter))
 B = (0.5*SlabDiameter-25)*sin(PII/3-angle(3,Iter))*
&    sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
 C = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
```

```
&     cos(PII/3+angle(3,Iter))*
&     sin(Aphad(3,Iter))
  D = (0.5*SlabDiameter-25)*sin(PII/3+angle(3,Iter))*
&     sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
  R(3) = atan(abs(A/B)*Deflection) + atan(abs(C/D)*Deflection)

C     ----- Calculate Moments -----

  Length = SlabDiameter/2
  Scale = 1.0
  Scale = Scale * (SlabDepth * SlabDepth)
&             / (BeamDepth * BeamDepth)

  ex = 2.71828182845905


  If (Choice.eq.1) then
  A =-22.983574
  B = 510.82594
  C = 1096.4253
  D = 399.89536
  E = 13.021289

  n = 1
  Do while (n.LE.NumYieldLines)
  U(n)=A+B*ex**(-C*R(n))+D*ex**(-E*R(n))
  n = n + 1
  End do
  End If


  If (Choice.eq.2) then
  A = 713.8233
  B = 1548.2115
  C = 122046.4
  D =-18049.989
  E = 3841417.1
  F = 520996.77
  G = 887480.45
  H =-993912.8
```

```
n = 1
Do while(n.LE.NumYieldLines)
U(n)=(A+C*R(n)+E*R(n)**2+G*R(n)**3)/
&    (1+B*R(n)+D*R(n)**2+F*R(n)**3+H*R(n)**4)
n = n +1
End do
End If


If (Choice.eq.4) then
A = 947.15784
B =-102.30554
C =-157916.81
D = 1355264.8
E = 1.4326672*100000000
F =-5368459.4
G =-80209796
H = 1.3639758*100000000
I = 95714037
J =-1.333125*100000000
K = 4167006.1

n = 1
Do while (n.LE.NumYieldLines)
U(n)=(A+C*R(n)+E*R(n)**2+G*R(n)**3+I*R(n)**4+K*R(n)**5)/
&    (1+B*R(n)+D*R(n)**2+F*R(n)**3+H*R(n)**4+J*R(n)**5)
n = n + 1
End Do
End If


If (Choice.eq.3) then
A = 1015.3096
B = 536.09064
C =-103638.9
D = 456002.81
E = 1.4254586*100000000
F = 9051626.8
G =-3311075.5
```

```
      H = 18405073
      I = 6687586.3
      J =-43461108

      n = 1
      Do while (n.LE.NumYieldLines)
      U(n)=(A+C*R(n)+E*R(n)**2+G*R(n)**3+I*R(n)**4)/
     &     (1+B*R(n)+D*R(n)**2+F*R(n)**3+H*R(n)**4+J*R(n)**5)
      n = n + 1
      End Do
      End If


C     ----- Calcualte load capacity by virtual work theorem -----
C     ----- CrackCapacity = Scale*Uint/deflection -----

      CrackCapacity=(U(1)*R(1)+U(2)*R(2)+U(3)*R(3))*Length/deflection

C     ----- Convert from kN to N -----

      CrackCapacity = Scale * CrackCapacity * 1000 / Beamwidth
      Capacity = CrackCapacity

      End If


      End


C     ----------------------
      Subroutine CalcAngle

C     ----- Parameters -----

      Real PI,s1,s2,s3,c1p,c2p,c3p,c1m,c2m,c3m,sq3,A1,B1,C1
      Real c13,c21,c32,s13,s21,s32,a2,a3,b2,b3,Delta

C     ----- Iteration Variables -----

      Integer Niter
```

```
      Integer Iter
      Common /Iteration/ Niter, Iter

C     ----- Initial Random Variable -----

      Real IniVar1,IniVar2,IniVar3
      Common /RandomData/ Inivar1,IniVar2,IniVar3

C     ----- Declare of Yield Line Data -----

      Integer NumYieldLines
      Real Angle(3,10000)
      Real EndX(3)
      Real EndY(3)
      Real Aphad(3,10000)

      Common /LineData/ NumYieldLines, Angle, Aphad
      Common /LineData/ EndX, EndY


      PI=3.14159265358979
      Angle(1,Iter+1)=(PI/180)*13.037712*(-alog(IniVar1))**(1/1.108481)
      Angle(2,Iter+1)=(PI/180)*13.037712*(-alog(IniVar2))**(1/1.108481)
      Angle(3,Iter+1)=(PI/180)*13.037712*(-alog(IniVar3))**(1/1.108481)
      If (IniVar3.le.0.5) Angle(1,Iter+1)=-Angle(1,Iter+1)
      If (IniVar1.le.0.5) Angle(2,Iter+1)=-Angle(2,Iter+1)
      If (IniVar2.le.0.5) Angle(3,Iter+1)=-Angle(3,Iter+1)
      If (abs(Angle(1,Iter+1)).gt.PI/3) Angle(1,Iter+1)=Angle(1,Iter)
      If (abs(Angle(2,Iter+1)).gt.PI/3) Angle(2,Iter+1)=Angle(2,Iter)
      If (abs(Angle(3,Iter+1)).gt.PI/3) Angle(3,Iter+1)=Angle(3,Iter)

      s1=sin(Angle(1,Iter+1))
      s2=sin(Angle(2,Iter+1))
      s3=sin(Angle(3,Iter+1))
      c1p=cos(Angle(1,Iter+1)+PI/6)
      c2p=cos(Angle(2,Iter+1)+PI/6)
      c3p=cos(Angle(3,Iter+1)+PI/6)
      c1m=cos(Angle(1,Iter+1)-PI/6)
      c2m=cos(Angle(2,Iter+1)-PI/6)
      c3m=cos(Angle(3,Iter+1)-PI/6)
```

```
  c13=cos(PI/3-Angle(1,Iter+1)+Angle(3,Iter+1))
  c21=cos(PI/3-Angle(2,Iter+1)+Angle(1,Iter+1))
  c32=cos(PI/3-Angle(3,Iter+1)+Angle(2,Iter+1))
  s13=sin(PI/3-Angle(1,Iter+1)+Angle(3,Iter+1))
  s21=sin(PI/3-Angle(2,Iter+1)+Angle(1,Iter+1))
  s32=sin(PI/3-Angle(3,Iter+1)+Angle(2,Iter+1))
  sq3=sqrt(3)

  a2=c2p*(sq3*s3*c32+c3m*s32)-sq3*s2*(c3m*c32-sq3*s3*s32)
  a3=c2m*(c3m*c32-sq3*s3*s32)
  b2=c2p*c32*c21+s32*sq3*s2*c21+s32*c2m*s21
  b3=-s21*(c2p*c32+sq3*s32*s2)+s32*c2m*c21
  A1=(a3*s21-a2*c21)*(-sq3*s1*s13+c1m*c13)
&   +b2*c3p*(sq3*s1*c13+c1m*s13)
  B1=-c1p*s13*(a3*s21-a2*c21)+(a2*s21+a3*c21)*(c1m*c13-sq3*s1*s13)
&   +c3p*(b2*c1p*c13+b3*(sq3*s1*c13+c1m*s13))
  C1=b3*c1p*c3p*c13-(a2*s21+a3*c21)*c1p*s13
  Delta=abs(B1*B1-4*A1*C1)
  If(A1.eq.0) Aphad(1,Iter+1)=atan(-B1/C1)
  If(A1.eq.0.and.C1.eq.0) Aphad(1,Iter+1)=0
  If(A1.ne.0) Aphad(1,Iter+1)=atan((-B1+sqrt(Delta))/(2*A1))

  a2=c3p*(sq3*s1*c13+c1m*s13)-sq3*s3*(c1m*c13-sq3*s1*s13)
  a3=c3m*(c1m*c13-sq3*s1*s13)
  b2=c3p*c13*c32+s13*sq3*s3*c32+s13*c3m*s32
  b3=-s32*(c3p*c13+sq3*s13*s3)+s13*c3m*c32
  A1=(a3*s32-a2*c32)*(-sq3*s2*s21+c2m*c21)
&   +b2*c1p*(sq3*s2*c21+c2m*s21)
  B1=-c2p*s21*(a3*s32-a2*c32)+(a2*s32+a3*c32)*(c2m*c21-sq3*s2*s21)
&   +c1p*(b2*c2p*c21+b3*(sq3*s2*c21+c2m*s21))
  C1=b3*c1p*c2p*c21-(a2*s32+a3*c32)*c2p*s21
  Delta=abs(B1*B1-4*A1*C1)
  If(A1.eq.0) Aphad(2,Iter+1)=atan(-B1/C1)
  If(A1.eq.0.and.C1.eq.0) Aphad(2,Iter+1)=0
  If(A1.ne.0) Aphad(2,Iter+1)=atan((-B1+sqrt(Delta))/(2*A1))

  a2=c1p*(sq3*s2*c21+c2m*s21)-sq3*s1*(c2m*c21-sq3*s2*s21)
  a3=c1m*(c2m*c21-sq3*s2*s21)
  b2=c1p*c21*c13+s21*sq3*s1*c13+s21*c1m*s13
  b3=-s13*(c1p*c21+sq3*s21*s1)+s21*c1m*c13
```

```
      A1=(a3*s13-a2*c13)*(-sq3*s3*s32+c3m*c32)
     &    +b2*c2p*(sq3*s3*c32+c3m*s32)
      B1=-c3p*s32*(a3*s13-a2*c13)+(a2*s13+a3*c13)*(c3m*c32-sq3*s3*s32)
     &    +c2p*(b2*c3p*c32+b3*(sq3*s3*c32+c3m*s32))
      C1=b3*c2p*c3p*c32-(a2*s13+a3*c13)*c3p*s32
      Delta=abs(B1*B1-4*A1*C1)
      If(A1.eq.0) Aphad(3,Iter+1)=atan(-B1/C1)
      If(A1.eq.0.and.C1.eq.0) Aphad(3,Iter+1)=0
      If(A1.ne.0) Aphad(3,Iter+1)=atan((-B1+sqrt(Delta))/(2*A1))

      End

C     ---------------------------------------------------
      Real Function LookUp(Rotation,Size,RotArray,ValArray)

C     ----- Parameters -----

      Real Rotation
      Integer Size
      Real RotArray(1001)
      Real ValArray(1001)

      Integer n
      Real LowerRot
      Real UpperRot
      Real LowerVal
      Real UpperVal

      n = 1
      Do while ((RotArray(n) < Rotation) .and. (n.LE.Size ))
      n = n + 1
      End do

      If (n .eq. 1) then
      LookUp = ValArray(1)
      End if

      If ((n > 1) .and. (n.LE.Size)) then
      LowerRot = RotArray(n-1)
      UpperRot = RotArray(n)
```

```
      LowerVal = ValArray(n-1)
      UpperVal = ValArray(n)
      LookUp = LowerVal + (UpperVal - LowerVal) *
     &        (Rotation - LowerRot) / (UpperRot - LowerRot)
      End If

      If (n > Size) then
      LookUp = ValArray(Size)
      End If

      End

C     --------------------------------------------------
      Subroutine SaveSlabCurve

C     ----- Variables -----

      Character*(1)  Selection
      Character*(50) FileName

      Print*,"SAVE SLAB RESULTS"
      Print*,"__________________"
      Print*," "
      Print*,"Save the output results ? (y/n) "
      Read*,selection

      If((Selection.eq."y").or.(Selection.eq."Y")) then
      Call GetFileName( FileName )

      Print*," "
      Print*,"Saving to ", FileName, "..."

      Call OutputSlabInfo(FileName)

      Print*," "
      Print*,"Done. "

      End if

      End
```

```
C      --------------------------------------------------------
       Subroutine OutputSlabInfo(FileName)

C      ----- Parameters -----

       Character*(50) FileName

       Integer Niter
       Integer Iter
       Common /Iteration/ Niter, Iter

C      ----- Declare of Slab Variables -----

       Real SlabDiameter
       Real SlabDepth

       Common /SlabData/ SlabDiameter, SlabDepth

C      ----- Declare of Yield Line Data -----

       Integer NumYieldLines
       Real Angle(3,10000)
       Real EndX(3)
       Real EndY(3)
       Real Aphad(3,10000)

       Common /LineData/ NumYieldLines, Angle, Aphad
       Common /LineData/ EndX, EndY

C      ----- Output Data -----

       Integer NumSlabPoints

       Real SlabDeflection(1001)
       Real SlabCapacity(1001)
       Real SlabDeflection2(10000)
       Real SlabCapacity2(10000)
       Real PeakLoad(10000)
```

```
      Common /OutputData/ NumSlabPoints,PeakLoad
      Common /OutputData/ SlabDeflection, SlabCapacity
      Common /OutputData/ SlabDeflection2,SlabCapacity2

C      ----- Variables -----

      Integer n,m

C      --------------------------------------------------------

      Open(Unit=1, File=FileName, Status='NEW')

      Write(Unit=1, Fmt=610) SlabDiameter, SlabDepth
 610  Format(F10.4, T12, F10.4)

      Write(Unit=1, Fmt=620) NumYieldLines
 620  Format(I10)

      n = 1
      Do while (n.le.Niter)
      Write(Unit=1, Fmt=630) (Angle(m,n), m=1,3)
 630  Format( T12, 3 F12.8 )
      n = n + 1
      End do

      Write(Unit=1, Fmt=640) NumSlabPoints
 640  Format(I10)

      n = 1
      Do while (n.le.Niter)
      Write(Unit=1, Fmt=650) SlabDeflection2(n),
    &           SlabCapacity2(n),PeakLoad(n)
 650  Format(F10.6, T12, F12.4, F12.4)
      n = n + 1
      End Do

      EndFile(Unit=1)
      Close(Unit =1)

      End
```

1.2.2. Procedures for Monte Carlo Analysis of RD Panel for Different Thickness Types

The main body of the program is similar to the first program. The difference is the procedure used to calculate the capacity which is shown below for three sets of concrete (see Chapter 6 in Volume 1).

1.2.2.1. MCSTV1.for (Concrete Set 1)

```
C     -------------------------------------------------
            Subroutine CalcCapacity(Deflection,Capacity,NSP)

            Real ex
            Real Deflection
            Real Capacity

C     ----- Variables -----

            Real*8 A,B,C,D,E,F,G,H,I,J,K,PII,Y
            Real R(12),U(12)
            Real Length
            Integer*4 n
            Real Scale
            Real CrackCapacity

C     ----- Iteration Variables -----

            Integer Niter
            Integer Iter
            Common /Iteration/ Niter, Iter

C     ----- Initial Random Variable -----

            Real IniVar1,IniVar2,IniVar3
            Common /RandomData/ Inivar1,IniVar2,IniVar3

C     ----- Declare of Yield Line Data -----
```

```
      Integer NumYieldLines
      Real Angle(3,10000)
      Real EndX(3)
      Real EndY(3)
      Real Aphad(3,10000)

      Common /LineData/ NumYieldLines, Angle, Aphad
      Common /LineData/ EndX, EndY

C     ----- Beam Data Variables -----

      Real BeamWidth
      Real BeamLength
      Real BeamDepth
      Integer NumBeamPoints
      Real BeamRotation(1001)
      Real BeamMoment(1001)

      Common /BeamData/ BeamWidth, BeamLength, BeamDepth
      Common /BeamData/ NumBeamPoints
      Common /BeamData/ BeamRotation, BeamMoment

C     ----- Declare of Slab Variables -----

      Real SlabDiameter
      Real SlabDepth

      Common /SlabData/ SlabDiameter, SlabDepth

C     ----- Other Data -----

      Integer Choice
      Common /OtherData/Choice

C     -------------------------------------------------

      Capacity = 0
      PII = 3.14159265358979
      Scale = 1.0
      Scale = Scale*(SlabDepth*SlabDepth)
```

```
&     /(BeamDepth*BeamDepth)


      If (NSP.eq.1) then

      Length=SlabDiameter/2

      A = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
&    cos(PII/3-angle(1,Iter))*
&    sin(Aphad(1,Iter))
      B = (0.5*SlabDiameter-25)*sin(PII/3-angle(1,Iter))*
&    sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
      C = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
&    cos(PII/3+angle(1,Iter))*
&    sin(Aphad(1,Iter))
      D = (0.5*SlabDiameter-25)*sin(PII/3+angle(1,Iter))*
&    sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
      R(1) = (A/B) + (C/D)
      A = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
&    cos(PII/3-angle(2,Iter))*
&    sin(Aphad(2,Iter))
      B = (0.5*SlabDiameter-25)*sin(PII/3-angle(2,Iter))*
&    sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
      C = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
&    cos(PII/3+angle(2,Iter))*
&    sin(Aphad(2,Iter))
      D = (0.5*SlabDiameter-25)*sin(PII/3+angle(2,Iter))*
&    sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
      R(2) = (A/B) + (C/D)
      A = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
&    cos(PII/3-angle(3,Iter))*
&    sin(Aphad(3,Iter))
      B = (0.5*SlabDiameter-25)*sin(PII/3-angle(3,Iter))*
&    sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
      C = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
&    cos(PII/3+angle(3,Iter))*
&    sin(Aphad(3,Iter))
      D = (0.5*SlabDiameter-25)*sin(PII/3+angle(3,Iter))*
&    sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
```

```
R(3) = (A/B) + (C/D)


mom = 0.06901*Beamdepth**2.18

If (Choice.eq.1) then
Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
End IF

If (Choice.eq.2) then
Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
End IF

If (Choice.eq.3) then
Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
End IF

If (Choice.eq.4) then
Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
End IF

If (Choice.eq.5) then
Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
End IF

If (Choice.eq.6) then
Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
End IF


End If


If (NSP.gt.1) then

A = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
& cos(PII/3-angle(1,Iter))*
& sin(Aphad(1,Iter))
B = (0.5*SlabDiameter-25)*sin(PII/3-angle(1,Iter))*
& sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
```

```
      C = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
     &  cos(PII/3+angle(1,Iter))*
     &  sin(Aphad(1,Iter))
      D = (0.5*SlabDiameter-25)*sin(PII/3+angle(1,Iter))*
     &  sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
      R(1) = atan(abs(A/B)*Deflection) + atan(abs(C/D)*Deflection)
      A = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
     &  cos(PII/3-angle(2,Iter))*
     &  sin(Aphad(2,Iter))
      B = (0.5*SlabDiameter-25)*sin(PII/3-angle(2,Iter))*
     &  sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
      C = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
     &  cos(PII/3+angle(2,Iter))*
     &  sin(Aphad(2,Iter))
      D = (0.5*SlabDiameter-25)*sin(PII/3+angle(2,Iter))*
     &  sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
      R(2) = atan(abs(A/B)*Deflection) + atan(abs(C/D)*Deflection)
      A = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
     &  cos(PII/3-angle(3,Iter))*
     &  sin(Aphad(3,Iter))
      B = (0.5*SlabDiameter-25)*sin(PII/3-angle(3,Iter))*
     &  sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
      C = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
     &  cos(PII/3+angle(3,Iter))*
     &  sin(Aphad(3,Iter))
      D = (0.5*SlabDiameter-25)*sin(PII/3+angle(3,Iter))*
     &  sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
      R(3) = atan(abs(A/B)*Deflection) + atan(abs(C/D)*Deflection)

C     ----- Calculate Moments -----

      Length = SlabDiameter/2
      Scale = 1.0
      Scale = Scale * (SlabDepth * SlabDepth)
     &         / (BeamDepth * BeamDepth)

      ex = 2.71828182845905

      If (Choice.eq.1) then
      A = 292.6926
```

```
        B =-61.476326
        C =-2468.3852
        D = 3236.954
        E = 209727.42
        F =-12724.148
        G =-23690.366
        H = 42006.236

        n = 1
        Do while (n.LE.NumYieldLines)
        U(n)=(A+C*R(n)**0.5+E*R(n)+G*R(n)**1.5)/
&  (1+B*R(n)**0.5+D*R(n)+F*R(n)**1.5+H*R(n)**2)
        n = n + 1
        End do
        End If


  If (Choice.eq.2) then
        A = 403.83835
        B = 806.88082
        C = 62241.924
        D =-7857.8154
        E = 667764.61
        F = 192054.81
        G = 14631.97
        H =-390069.55
        I =-2498454.1

        n = 1
        Do while (n.LE.NumYieldLines)
        U(n)=(A+C*R(n)+E*R(n)**2+G*R(n)**3+I*R(n)**4)/
&  (1+B*R(n)+D*R(n)**2+F*R(n)**3+H*R(n)**4)
        n = n + 1
        End do
        End If


  If (Choice.eq.3) then
        A = 642.36799
        B =-45.154592
```

```
C =-10133.214
D = 2283.6486
E = 302277.6
F =-13719.892
G =-576091.75
H = 41169.49
I = 1227955.4
J =-15469.974
K =-586163.51

n = 1
Do while (n.LE.NumYieldLines)
U(n)=(A+C*R(n)**0.5+E*R(n)+G*R(n)**1.5+I*R(n)**2+K*R(n)**2.5)/
& (1+B*R(n)**0.5+D*R(n)+F*R(n)**1.5+H*R(n)**2+J*R(n)**2.5)
n = n + 1
End do
End If


If (Choice.eq.4) then
A = 1002.9076
B = 1114.5109
C = 119592.76
D =-20982.185
E = 6682982.3
F = 853051.17
G =-9852919.7
H =-2828304.1
I = 33155203
J = 4051085.1

n = 1
Do while (n.LE.NumYieldLines)
U(n)=(A+C*R(n)+E*R(n)**2+G*R(n)**3+I*R(n)**4)
& /(1+B*R(n)+D*R(n)**2+F*R(n)**3+H*R(n)**4+J*R(n)**5)
n = n + 1
End do
End If
```

```
      If (Choice.eq.5) then
          A = 1225.8073
          B = 1339.1766
          C = 499469.44
          D =-6259.985
          E = 13559127
          F = 957952.74
          G = 106308.12
          H =-868876.82

          n = 1
          Do while (n.LE.NumYieldLines)
          U(n)=(A+C*R(n)+E*R(n)**2+G*R(n)**3)/
     &  (1+B*R(n)+D*R(n)**2+F*R(n)**3+H*R(n)**4)
          n = n + 1
          End do
          End If


          If (Choice.eq.6) then
          A = 1482.1973
          B = 1053.0044
          C = 207639.38
          D =-27647.227
          E = 7891246.5
          F = 992304.57
          G = 134795.37
          H =-2909154.4
          I = 1.5804941*100000000
          J = 7756945.9

          n = 1
          Do while (n.LE.NumYieldLines)
          U(n)=(A+C*R(n)+E*R(n)**2+G*R(n)**3+I*R(n)**4)/
     &  (1+B*R(n)+D*R(n)**2+F*R(n)**3+H*R(n)**4+J*R(n)**5)
          n = n + 1
          End do
          End If

C     ----- Calcualte load capacity by virtual work theorem -----
```

```
C      ----- CrackCapacity = Scale*Uint/deflection -----

       CrackCapacity = (U(1)*R(1)+U(2)*R(2)+U(3)*R(3))*Length/deflection

C      ----- Convert from kN to N -----

       CrackCapacity = Scale * CrackCapacity * 1000 / Beamwidth
       Capacity = CrackCapacity

       End If

       End
```

1.2.2.2. MCSTV2.for (Concrete Set 2)

```
C     --------------------------------------------------
            Subroutine CalcCapacity(Deflection,Capacity,NSP)

            Real ex
            Real Deflection
            Real Capacity

C     ----- Variables -----

            Real*8 A,B,C,D,E,F,G,H,I,J,K,PII,Y
            Real R(12),U(12)
            Real Length
            Integer*4 n
            Real Scale
            Real CrackCapacity

C     ----- Iteration Variables -----

            Integer Niter
            Integer Iter
            Common /Iteration/ Niter, Iter

C     ----- Initial Random Variable -----

            Real IniVar1,IniVar2,IniVar3
            Common /RandomData/ Inivar1,IniVar2,IniVar3

C     ----- Declare of Yield Line Data -----

            Integer NumYieldLines
            Real Angle(3,10000)
            Real EndX(3)
            Real EndY(3)
            Real Aphad(3,10000)

            Common /LineData/ NumYieldLines, Angle, Aphad
            Common /LineData/ EndX, EndY
```

```
C     ----- Beam Data Variables -----

        Real BeamWidth
        Real BeamLength
        Real BeamDepth
        Integer NumBeamPoints
        Real BeamRotation(1001)
        Real BeamMoment(1001)

        Common /BeamData/ BeamWidth, BeamLength, BeamDepth
        Common /BeamData/ NumBeamPoints
        Common /BeamData/ BeamRotation, BeamMoment

C     ----- Declare of Slab Variables -----

        Real SlabDiameter
        Real SlabDepth

        Common /SlabData/ SlabDiameter, SlabDepth

C     ----- Other Data -----

        Integer Choice
        Common /OtherData/Choice

C     --------------------------------------------------

        Capacity = 0
        PII = 3.14159265358979
        Scale = 1.0
        Scale = Scale*(SlabDepth*SlabDepth)
   &    /(BeamDepth*BeamDepth)

        If (NSP.eq.1) then

        Length=SlabDiameter/2

        A = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
   &    cos(PII/3-angle(1,Iter))*
   &    sin(Aphad(1,Iter))
```

```
      B = (0.5*SlabDiameter-25)*sin(PII/3-angle(1,Iter))*
&    sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
      C = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
&    cos(PII/3+angle(1,Iter))*
&    sin(Aphad(1,Iter))
      D = (0.5*SlabDiameter-25)*sin(PII/3+angle(1,Iter))*
&    sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
      R(1) = (A/B) + (C/D)
      A = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
&    cos(PII/3-angle(2,Iter))*
&    sin(Aphad(2,Iter))
      B = (0.5*SlabDiameter-25)*sin(PII/3-angle(2,Iter))*
&    sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
      C = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
&    cos(PII/3+angle(2,Iter))*
&    sin(Aphad(2,Iter))
      D = (0.5*SlabDiameter-25)*sin(PII/3+angle(2,Iter))*
&    sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
      R(2) = (A/B) + (C/D)
      A = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
&    cos(PII/3-angle(3,Iter))*
&    sin(Aphad(3,Iter))
      B = (0.5*SlabDiameter-25)*sin(PII/3-angle(3,Iter))*
&    sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
      C = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
&    cos(PII/3+angle(3,Iter))*
&    sin(Aphad(3,Iter))
      D = (0.5*SlabDiameter-25)*sin(PII/3+angle(3,Iter))*
&    sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
      R(3) = (A/B) + (C/D)


      mom = 0.29418*Beamdepth**1.8

      If (Choice.eq.1) then
      Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
      End IF

      If (Choice.eq.2) then
      Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
```

```
        End IF

        If (Choice.eq.3) then
        Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
        End IF

        If (Choice.eq.4) then
        Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
        End IF

        If (Choice.eq.5) then
        Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
        End IF

        If (Choice.eq.6) then
        Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
        End IF

        End If

        If (NSP.gt.1) then

        A = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
    &   cos(PII/3-angle(1,Iter))*
    &   sin(Aphad(1,Iter))
        B = (0.5*SlabDiameter-25)*sin(PII/3-angle(1,Iter))*
    &   sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
        C = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
    &   cos(PII/3+angle(1,Iter))*
    &   sin(Aphad(1,Iter))
        D = (0.5*SlabDiameter-25)*sin(PII/3+angle(1,Iter))*
    &   sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
        R(1) = atan(abs(A/B)*Deflection) + atan(abs(C/D)*Deflection)
        A = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
    &   cos(PII/3-angle(2,Iter))*
    &   sin(Aphad(2,Iter))
        B = (0.5*SlabDiameter-25)*sin(PII/3-angle(2,Iter))*
    &   sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
        C = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
    &   cos(PII/3+angle(2,Iter))*
```

```
     &    sin(Aphad(2,Iter))
          D = (0.5*SlabDiameter-25)*sin(PII/3+angle(2,Iter))*
     &    sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
          R(2) = atan(abs(A/B)*Deflection) + atan(abs(C/D)*Deflection)
          A = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
     &    cos(PII/3-angle(3,Iter))*
     &    sin(Aphad(3,Iter))
          B = (0.5*SlabDiameter-25)*sin(PII/3-angle(3,Iter))*
     &    sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
          C = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
     &    cos(PII/3+angle(3,Iter))*
     &    sin(Aphad(3,Iter))
          D = (0.5*SlabDiameter-25)*sin(PII/3+angle(3,Iter))*
     &    sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
          R(3) = atan(abs(A/B)*Deflection) + atan(abs(C/D)*Deflection)

C    ----- Calculate Moments -----

          Length = SlabDiameter/2
          Scale = 1.0
          Scale = Scale * (SlabDepth * SlabDepth)
     &           / (BeamDepth * BeamDepth)

          ex = 2.71828182845905

          If (Choice.eq.1) then
          A = 406.62524
          B = 1814.6795
          C = 21525.276
          D = 6729.3058
          E = 5100517.7
          F = 467569.82

          n = 1
          Do while (n.LE.NumYieldLines)
          U(n)=(A+C*R(n)+E*R(n)**2)/
     & (1+B*R(n)+D*R(n)**2+F*R(n)**3)
          n = n + 1
          End do
          End If
```

```
If (Choice.eq.2) then
        A = 530.65677
        B =-12.314605
        C =-16175.535
        D = 35.124923
        E = 182818.92
        F = 7365.7654
        G =-331705.15
        H =-33087.46
        I = 231930.84
        J = 47648.991

        n = 1
        Do while (n.LE.NumYieldLines)
        U(n)=(A+C*R(n)**0.5+E*R(n)+G*R(n)**1.5+I*R(n)**2)/
&  (1+B*R(n)**0.5+D*R(n)+F*R(n)**1.5+H*R(n)**2+J*R(n)**2.5)
        n = n + 1
        End do
        End If


If (Choice.eq.3) then
        A = 577.1513
        B =-36.313461
        C =-15515.221
        D = 921.22987
        E = 173865.69
        F =-3583.5537
        G =-318143.65
        H = 6496.0488
        I = 212208.6

        n = 1
        Do while (n.LE.NumYieldLines)
        U(n)=(A+C*R(n)**0.5+E*R(n)+G*R(n)**1.5+I*R(n)**2)
&  /(1+B*R(n)**0.5+D*R(n)+F*R(n)**1.5+H*R(n)**2)
        n = n + 1
        End do
```

```
        End If


  If (Choice.eq.4) then
        A = 694.42783
        B = 539.37078
        C =-104366.93
        D = 17700.376
        E = 13437925
        F = 425487.57
        G = 257673.14
        H = 1226770.3
        I = 11631104

        n = 1
        Do while (n.LE.NumYieldLines)
        U(n)=(A+C*R(n)+E*R(n)**2+G*R(n)**3+I*R(n)**4)
&  /(1+B*R(n)+D*R(n)**2+F*R(n)**3+H*R(n)**4)
        n = n + 1
        End do
        End If


  If (Choice.eq.5) then
        A = 1296.1096
        B = 2182.9872
        C = 97629.259
        D =-37784.638
        E = 11162577
        F = 916116.96
        G = 454754.57

        n = 1
        Do while (n.LE.NumYieldLines)
        U(n)=(A+C*R(n)+E*R(n)**2+G*R(n)**3)/
&  (1+B*R(n)+D*R(n)**2+F*R(n)**3)
        n = n + 1
        End do
        End If
```

```
If (Choice.eq.6) then
A = 1242.5276
B = 1367.7329
C = 139040.35
D =-29402.99
E = 4165067.1
F = 521333.6

n = 1
Do while (n.LE.NumYieldLines)
U(n)=(A+C*R(n)+E*R(n)**2)/
& (1+B*R(n)+D*R(n)**2+F*R(n)**3)
n = n + 1
End do
End If



C     ----- Calcualte load capacity by virtual work theorem -----
C     ----- CrackCapacity = Scale*Uint/deflection -----

CrackCapacity = (U(1)*R(1)+U(2)*R(2)+U(3)*R(3))*Length/deflection

C     ----- Convert from kN to N -----

CrackCapacity = Scale * CrackCapacity * 1000 / Beamwidth
Capacity = CrackCapacity

End If

End
```

1.2.2.3. MCSTV3.for (Concrete Set 3)

```
C       --------------------------------------------------
            Subroutine CalcCapacity(Deflection,Capacity,NSP)

            Real ex
            Real Deflection
            Real Capacity

C       ----- Variables -----

            Real*8 A,B,C,D,E,F,G,H,I,J,K,PII,Y
            Real R(12),U(12)
            Real Length
            Integer*4 n
            Real Scale
            Real CrackCapacity

C       ----- Iteration Variables -----

            Integer Niter
            Integer Iter
            Common /Iteration/ Niter, Iter

C       ----- Initial Random Variable -----

            Real IniVar1,IniVar2,IniVar3
            Common /RandomData/ Inivar1,IniVar2,IniVar3

C       ----- Declare of Yield Line Data -----

            Integer NumYieldLines
            Real Angle(3,10000)
            Real EndX(3)
            Real EndY(3)
            Real Aphad(3,10000)

            Common /LineData/ NumYieldLines, Angle, Aphad
            Common /LineData/ EndX, EndY
```

```
C      ----- Beam Data Variables -----

          Real BeamWidth
          Real BeamLength
          Real BeamDepth
          Integer NumBeamPoints
          Real BeamRotation(1001)
          Real BeamMoment(1001)

          Common /BeamData/ BeamWidth, BeamLength, BeamDepth
          Common /BeamData/ NumBeamPoints
          Common /BeamData/ BeamRotation, BeamMoment

C      ----- Declare of Slab Variables -----

          Real SlabDiameter
          Real SlabDepth

          Common /SlabData/ SlabDiameter, SlabDepth

C      ----- Other Data -----

          Integer Choice
          Common /OtherData/Choice

C      --------------------------------------------------

          Capacity = 0
          PII = 3.14159265358979
          Scale = 1.0
          Scale = Scale*(SlabDepth*SlabDepth)
   &      /(BeamDepth*BeamDepth)

          If (NSP.eq.1) then

          Length=SlabDiameter/2

          A = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
   &     cos(PII/3-angle(1,Iter))*
   &     sin(Aphad(1,Iter))
```

```
        B = (0.5*SlabDiameter-25)*sin(PII/3-angle(1,Iter))*
     &  sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
        C = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
     &  cos(PII/3+angle(1,Iter))*
     &  sin(Aphad(1,Iter))
        D = (0.5*SlabDiameter-25)*sin(PII/3+angle(1,Iter))*
     &  sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
        R(1) = (A/B) + (C/D)
        A = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
     &  cos(PII/3-angle(2,Iter))*
     &  sin(Aphad(2,Iter))
        B = (0.5*SlabDiameter-25)*sin(PII/3-angle(2,Iter))*
     &  sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
        C = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
     &  cos(PII/3+angle(2,Iter))*
     &  sin(Aphad(2,Iter))
        D = (0.5*SlabDiameter-25)*sin(PII/3+angle(2,Iter))*
     &  sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
        R(2) = (A/B) + (C/D)
        A = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
     &  cos(PII/3-angle(3,Iter))*
     &  sin(Aphad(3,Iter))
        B = (0.5*SlabDiameter-25)*sin(PII/3-angle(3,Iter))*
     &  sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
        C = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
     &  cos(PII/3+angle(3,Iter))*
     &  sin(Aphad(3,Iter))
        D = (0.5*SlabDiameter-25)*sin(PII/3+angle(3,Iter))*
     &  sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
        R(3) = (A/B) + (C/D)


        mom = 0.32*Beamdepth**1.793

        If (Choice.eq.1) then
        Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
        End IF

        If (Choice.eq.2) then
        Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
```

```
End IF

If (Choice.eq.3) then
Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
End IF

If (Choice.eq.4) then
Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
End IF

If (Choice.eq.5) then
Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
End IF

If (Choice.eq.6) then
Capacity =1000*Scale*Length*mom*(R(1)+R(2)+R(3))/Beamwidth
End IF


End If


If (NSP.gt.1) then

 A = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
& cos(PII/3-angle(1,Iter))*
& sin(Aphad(1,Iter))
 B = (0.5*SlabDiameter-25)*sin(PII/3-angle(1,Iter))*
& sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
 C = sin(Aphad(1,Iter)+PII/3-angle(1,Iter))-
& cos(PII/3+angle(1,Iter))*
& sin(Aphad(1,Iter))
 D = (0.5*SlabDiameter-25)*sin(PII/3+angle(1,Iter))*
& sin(Aphad(1,Iter)+PII/3-angle(1,Iter))
 R(1) = atan(abs(A/B)*Deflection) + atan(abs(C/D)*Deflection)
 A = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
& cos(PII/3-angle(2,Iter))*
& sin(Aphad(2,Iter))
 B = (0.5*SlabDiameter-25)*sin(PII/3-angle(2,Iter))*
& sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
```

```
            C = sin(Aphad(2,Iter)+PII/3-angle(2,Iter))-
     &     cos(PII/3+angle(2,Iter))*
     &     sin(Aphad(2,Iter))
            D = (0.5*SlabDiameter-25)*sin(PII/3+angle(2,Iter))*
     &     sin(Aphad(2,Iter)+PII/3-angle(2,Iter))
            R(2) = atan(abs(A/B)*Deflection) + atan(abs(C/D)*Deflection)
            A = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
     &     cos(PII/3-angle(3,Iter))*
     &     sin(Aphad(3,Iter))
            B = (0.5*SlabDiameter-25)*sin(PII/3-angle(3,Iter))*
     &     sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
            C = sin(Aphad(3,Iter)+PII/3-angle(3,Iter))-
     &     cos(PII/3+angle(3,Iter))*
     &     sin(Aphad(3,Iter))
            D = (0.5*SlabDiameter-25)*sin(PII/3+angle(3,Iter))*
     &     sin(Aphad(3,Iter)+PII/3-angle(3,Iter))
            R(3) = atan(abs(A/B)*Deflection) + atan(abs(C/D)*Deflection)

C     ----- Calculate Moments -----

            Length = SlabDiameter/2
            Scale = 1.0
            Scale = Scale * (SlabDepth * SlabDepth)
     &              / (BeamDepth * BeamDepth)

            ex = 2.71828182845905

            If (Choice.eq.1) then
            A = 341.66396
            B = 2101.5751
            C = 242426.81
            D =-9959.0804
            E =-1524116.4
            F = 67742.289
            G = 4940043.2

            n = 1
            Do while (n.LE.NumYieldLines)
            U(n)=(A+C*R(n)+E*R(n)**2+G*R(n)**3)/
     & (1+B*R(n)+D*R(n)**2+F*R(n)**3)
```

```
        n = n + 1
        End do
        End If


    If (Choice.eq.2) then
        A = 623.68239
        B = 1751.7137
        C = 325783.49
        D =-24101.121
        E = 914280.22
        F = 687970.37
        G =-7653029.2
        H =-4678380.3
        I = 13484805
        J = 10931815

        n = 1
        Do while (n.LE.NumYieldLines)
        U(n)=(A+C*R(n)+E*R(n)**2+G*R(n)**3+I*R(n)**4)/
  &  (1+B*R(n)+D*R(n)**2+F*R(n)**3+H*R(n)**4+J*R(n)**5)
        n = n + 1
        End do
        End If


    If (Choice.eq.3) then
        A = 626.35298
        B = 1520.7264
        C = 354064.96
        D =-4759.2563
        E = 4768016
        F = 543498.54
        G =-7437108.4
        H =-1090171.8
        I = 23259773
        J = 1934504.2

        n = 1
        Do while (n.LE.NumYieldLines)
```

```
      U(n)=(A+C*R(n)+E*R(n)**2+G*R(n)**3+I*R(n)**4)
&  /(1+B*R(n)+D*R(n)**2+F*R(n)**3+H*R(n)**4+J*R(n)**5)
      n = n + 1
      End do
      End If


      If (Choice.eq.4) then
      A = 847.05186
      B = 968.89608
      C = 291244.09
      D =-15766.359
      E = 558385.75
      F = 401427.46
      G =-4823803.7
      H =-2540071.2
      I = 10456085
      J = 5533228.4

      n = 1
      Do while (n.LE.NumYieldLines)
      U(n)=(A+C*R(n)+E*R(n)**2+G*R(n)**3+I*R(n)**4)
&  /(1+B*R(n)+D*R(n)**2+F*R(n)**3+H*R(n)**4+J*R(n)**5)
      n = n + 1
      End do
      End If


  If (Choice.eq.5) then
      A = 744.58933
      B =-39.879862
      C = 8762.9557
      D = 2699.3008
      E = 446249.24
      F =-16874.351
      G = 10326.837
      H = 53562.754
      I = 633848.61

      n = 1
```

```
      Do while (n.LE.NumYieldLines)
      U(n)=(A+C*R(n)**0.5+E*R(n)+G*R(n)**1.5+I*R(n)**2)/
     & (1+B*R(n)**0.5+D*R(n)+F*R(n)**1.5+H*R(n)**2)
      n = n + 1
      End do
      End If


      If (Choice.eq.6) then
      A = 1275.2674
      B =-19.429832
      C =-17752.46
      D = 549.16336
      E = 236295.54
      F =-3655.5935
      G =-449008.19
      H = 10429.385
      I = 512931.67

      n = 1
      Do while (n.LE.NumYieldLines)
      U(n)=(A+C*R(n)**0.5+E*R(n)+G*R(n)**1.5+I*R(n)**2)/
     & (1+B*R(n)**0.5+D*R(n)+F*R(n)**1.5+H*R(n)**2)
      n = n + 1
      End do
      End If

C     ----- Calcualte load capacity by virtual work theorem -----
C     ----- CrackCapacity = Scale*Uint/deflection -----

      CrackCapacity = (U(1)*R(1)+U(2)*R(2)+U(3)*R(3))*Length/deflection

C     ----- Convert from kN to N -----

      CrackCapacity = Scale * CrackCapacity * 1000 / Beamwidth
      Capacity = CrackCapacity

      End If
      End
```

1.2.3. BEAMYLT.for

```
C  Monte Carlo analysis for crack modelling in fibre reinforced
C  shotcrete beam using yield line analysis
C  Author:    Vinh Tran
C  Commenced: 1st November 2002


C      MAIN PROGRAM

          Program Beam

          Data k,j,im,rm / 5701,3612,566927,566927.0/

          Integer Niter
          Integer Iter
          Common /Iteration/ Niter, Iter

          Real IniVar1,IniVar2
          Common /RandomData/ IniVar1,IniVar2


C      ----- Declare of Beam Variables -------

          Real BeamWidth
          Real BeamLength
          Real BeamDepth

          Integer NumBeamPoints
          Real BeamRota(1001)
          Real BeamMoment(1001)

          Common /BeamData/ BeamWidth, BeamLength, BeamDepth
          Common /BeamData/ NumBeamPoints
          Common /BeamData/ BeamRota, BeamMoment


C      ------Declare of Slab Variables ------

          Real SlabDiameter
```

```
      Real SlabDepth

      Common /SlabData/ SlabDiameter, SlabDepth

C     ------ Declare of Yield Line Data ------

      Integer NumYieldLines
      Real Angle(3,10000)
      Real EndX(3)
      Real EndY(3)

      Common /LineData/ NumYieldLines, Angle
      Common /LineData/ EndX, EndY

C     ------ Output Data ------

      Integer NumSlabPoints

      Real BeamRotation(1001)
      Real BeamCapacity(1001)
      Real BeamRotation2(10000)
      Real BeamCapacity2(10000)
      Real PeakLoad(10000)

      Common /OutputData/ NumSlabPoints,PeakLoad
      Common /OutputData/ BeamRotation, BeamCapacity
      Common /OutputData/ BeamRotation2,BeamCapacity2

C     ------ Other Variables --------

      Integer Choice

      Common /OtherData/Choice

C     --------------------------------------------------
      Character*(1) Response

      Call DisplayWelcome

      Print *, " Let start the input (y/n) ?  "
```

```
      Read *, Response

      If ((Response .eq. "y") .or. (Response .eq. "Y")) then
      Print *," Input Iteration Number = "
      Read*,Niter

C     Input the initial random number in (0,1)

      Print*," Please enter the random numbers in range (0,1)"
      Print*," Initial Variable = "
      Read*,IniVar1

      Call GetBeamInfo
      Call GetSlabInfo
      Call GetYieldLineInfo

C     ----- Start the Iteration Run -----

      Do 1 Iter=1,Niter

      Ix1=int(IniVar1*rm)
      Irand1=mod(j*ix1+k,im)
      IniVar1=(real(irand1)+0.5)/rm

      Call CalcSlabCurve
      Call CalcAngle

    1 Continue

      Call SaveSlabCurve

      End if
      End

C     --------------------------
      Subroutine DisplayWelcome

      Call system("cls")

      Print *, "    ÉÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ»"
```

```
      Print *, "    º      Centrally Loaded Beam 1.0       º"
      Print *, "    º  Copyright (C) 2000 by VINH TRAN    º"
      Print *, "    ÈÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍÍ¼"
      Print *, " "
      Print *, " "
      Print *, " "
      Print *, " "
      Print *, " "
      Print *, " "
      Print *, " "
      Print *, " "
      Print *, " "
      Print *, " "
      Print *, " "
      End

C     -------------------------------------------------------
      Subroutine GetBeamInfo

C     ------ Other Data ------

      Integer Choice

      Common /OtherData/Choice

      Choice = 0

      Do while ((Choice .ne. 1) .and. (Choice .ne. 2)
     &   .and. (Choice .ne. 3) .and. (Choice .ne. 4))

      Call system( "cls" )

      Print*,"BEAM TEST RESULTS"
      Print*,"_________________"
      Print*," "
      Print*," "
      Print*,"  1. Panel Test Results in Set 1"
      Print*,"  2. Panel Test Results in Set 2"
      Print*,"  3. Panel Test Results in Set 3"
      Print*,"  4. Panel Test Results in Set 4"
```

```
      Print*," "
      Print*,"  Enter The Choice =  "
      Read *, Choice

      End do

      Call GetBeamDimensions

      End

C     -------------------------------------------------------
      Subroutine OpenBeamInfo

      Integer n
      Character*(50) FileName

C     ----- Declare of Beam Variables ------

      Real BeamWidth
      Real BeamLength
      Real BeamDepth
      Integer NumBeamPoints
      Real BeamRota(1001)
      Real BeamMoment(1001)

      Common /BeamData/ BeamWidth, BeamLength, BeamDepth
      Common /BeamData/ NumBeamPoints
      Common /BeamData/ BeamRota, BeamMoment

C     -----------------------------

      Call GetFileName(FileName)

      Open(Unit=1, File=FileName, Status='OLD' )

      Read(Unit=1,Fmt=110) BeamLength, BeamWidth, BeamDepth
 110  Format(F10.4, T12, F10.4, T24, F10.4 )
      Read(Unit=1, Fmt=120) NumBeamPoints
 120  Format(I10)
```

```
      n = 1
      Do while (n.le.NumBeamPoints)
      Read(Unit=1, Fmt=130) BeamRota(n), BeamMoment(n)
 130  Format(F10.6, T12, F10.4)
      n = n + 1
      End Do

      EndFile(Unit=1)
      Close(Unit=1)

      End

C     ------------------------------------------------------
      Subroutine GetBeamDimensions

      Logical Finished

C     ----- Declare of Beam Variables -----

      Real BeamWidth
      Real BeamLength
      Real BeamDepth
      Integer NumBeamPoints
      Real BeamRota(1001)
      Real BeamMoment(1001)

      Common /BeamData/ BeamWidth, BeamLength, BeamDepth
      Common /BeamData/ NumBeamPoints
      Common /BeamData/ BeamRota, BeamMoment

C     --------------------------------------------------------

      Call system( "cls" )

      Print *, "BEAM DIMENSIONS"
      Print *, "________________"
      Print *, " "
      Print *, " "
      Print *, "Enter Beam Dimensions (mm)  "
```

```
Finished = .false.

Do while (.not.finished)
Print*,"Length =  "
Read*,BeamLength

If (BeamLength.LE.0) then
Print *, "ERROR: Length must be greater than 0."
Else
        Finished = .true.
End if
End Do

Finished=.false.

Do while (.not.finished)
Print*,"Width =  "
Read*,BeamWidth

If (BeamWidth.LE.0) then
Print*,"ERROR: Width must be greater than 0."
Else
        Finished=.true.
End If
End Do

Finished=.false.

Do while (.not.finished)
Print*,"Depth =  "
Read*,BeamDepth

If (BeamDepth.LE.0) then
Print*,"ERROR: Depth must be greater than 0."
Else
        Finished=.true.
End if
End Do
```

```
      Print*," "

      End

C     ------------------------------------------------------
      Subroutine GetBeamMeasurements

      Logical Finished
      Integer n

C     ----- Declare of Beam Variables ------

      Real BeamWidth
      Real BeamLength
      Real BeamDepth
      Integer NumBeamPoints
      Real BeamRota(1001)
      Real BeamMoment(1001)

      Common /BeamData/ BeamWidth, BeamLength, BeamDepth
      Common /BeamData/ NumBeamPoints
      Common /BeamData/ BeamRota, BeamMoment

C     ------------------------------------------------------

      Call system( "cls" )

      Print*,"MOMENT/ROTATION DATA POINTS"
      Print*,"________________________________"
      Print*," "
      Print*,"The results of the beam test must be input here"
      Print*,"For each rotation data point, the moment capacity "
      Print*,"have to be entered "
      Print*," "
      Print*,"Please enter the number of data points "

      Finished=.false.
      Do while (.not.finished)
      Print*,"Number of data points =  "
      Read *, NumBeamPoints
```

```
      If ((NumBeamPoints.LE.0) .or. (NumBeamPoints > 100)) then
      Print*,"ERROR: No. of points must be between 1 & 100."
      Else
            Finished = .true.
      End If
      End Do

      Print*," "

      n = 1
      Do while (n.LE.NumBeamPoints)
      Print*,"Point ", n, ": "
      Print*,"Rotation (in radians) = "
      Read*,BeamRota(n)
      Print*,"Moment (in Nmm) =  "
      Read*,BeamMoment(n)
      Print*," "
      n = n + 1
      End Do

      End

C     ------------------------------------------------------
      Subroutine SaveBeamInfo

      Character*(1)  Selection
      Character*(50) FileName

      Call system( "cls" )

      Print*,"SAVE BEAM INFORMATION"
      Print*,"_______________________"
      Print*," "
      Print*,"Do you want to save the beam information that "
      Print*,"you have just entered to a file (for use with "
      Print*,"other beams)?   (y/n)  "

      Read*,Selection
```

```
      If ((Selection.eq."y").or.(Selection.eq."Y")) then
      Call GetFileName( FileName )

      Print*," "
      Print*,"Saving to ", FileName, "..."

      Call OutputBeamInfo(FileName)

      Print*," "
      Print*,"Done. "

      End if

      End

C     -----------------------------------------------------
      Subroutine GetFileName(FileName)

C     ----- Parameters -----

      Character*(50) FileName

      Print*," "
      Print*,"Please enter the file name =  "
      Read*,FileName

      End

C     -----------------------------------------------------
      Subroutine OutputBeamInfo(FileName)

C     ----- Parameters -----

      Character*(50) FileName
      Integer n

C     ----- Declare of Beam Variables ------

      Real BeamWidth
      Real BeamLength
```

```
      Real BeamDepth
      Integer NumBeamPoints
      Real BeamRota(1001)
      Real BeamMoment(1001)

      Common /BeamData/ BeamWidth, BeamLength, BeamDepth
      Common /BeamData/ NumBeamPoints
      Common /BeamData/ BeamRota, BeamMoment

C   -----------------------------------------------------

      Open(Unit=1, File=FileName, Status='NEW')

      Write(Unit=1, Fmt=10) BeamLength, BeamWidth, BeamDepth
 10   Format(F10.4, T12, F10.4, T24, F10.4 )

      Write(Unit=1, Fmt=20) NumBeamPoints
 20   Format(I10)

      n = 1
      Do while ( n .le. NumBeamPoints )
      Write(Unit=1, Fmt=30) BeamRota(n), BeamMoment(n)
 30   Format(F10.6, T12, F10.4)
      n = n + 1
      End Do

      EndFile(Unit=1)
      Close(Unit=1)

      End

C   -----------------------------------------------------
      Subroutine GetSlabInfo

      Call system( "CLS" )

      Print*,"SLAB INFORMATION"
      Print*,"_________________"
      Print*," "
      Print*," "
```

```
      Print*," "

      Call GetSlabDimensions

      End

C     -------------------------------------------------------
      Subroutine GetSlabDimensions

C     ----- Declare of Slab Variables -----

      Real SlabDiameter
      Real SlabDepth

      Common /SlabData/ SlabDiameter, SlabDepth

      Logical Finished

      Print*,"Enter RDP Dimensions (mm)  "

      Finished=.false.
      Do while (.not.finished)
      Print*,"Diameter =  "
      Read*,SlabDiameter

      If (SlabDiameter.LE.0) then
      Print*,"ERROR: Diameter must be greater than 0."
      Else
      Finished=.true.
      End If
      End Do

      Finished=.false.
      Do while (.not.finished)
      Print*,"Depth =  "
      Read *,SlabDepth
      If (SlabDepth.LE.0) then
      Print*,"ERROR: Depth must be greater than 0."
      Else
      Finished=.true.
```

```
      End If
      End Do

      Print*," "

      End

C     -------------------------------------------------------
      Subroutine GetYieldLineInfo



      Integer Niter
      Integer Iter
      Common /Iteration/ Niter, Iter

      Real IniVar1,IniVar2
      Common /RandomData/ IniVar1,IniVar2

C     ----- Declare of Yield Line Data ------

      Integer NumYieldLines
      Real Angle(3,10000)
      Real EndX(3)
      Real EndY(3)

      Common /LineData/ NumYieldLines, Angle
      Common /LineData/ EndX, EndY

C     -------------------------------------------------

      NumYieldLines=3

C     ----- Convert all angles into radians -----

      PI=3.14159265358979
      Angle(1,1)=(PI/180)*13.037712*(-alog(IniVar1))**(1/1.108481)

      End

C     --------------------------------------------------
```

```
      Subroutine CalcSlabCurve

      Real LookUp
      Integer*4 n
      Real Rotation
      Real MinRotation
      Real MaxRotation
      Real DeltaRotation
      Real IniVar4

      Integer Niter
      Integer Iter
      Common /Iteration/ Niter, Iter

      Real IniVar1,IniVar2
      Common /RandomData/ IniVar1,IniVar2

C     ----- Declare of Yield Line Data -----

      Integer NumYieldLines
      Real Angle(3,10000)
      Real EndX(3)
      Real EndY(3)

      Common /LineData/ NumYieldLines, Angle
      Common /LineData/ EndX, EndY

C     ----- Output Data -----

      Integer NumBeamPoints

      Real BeamRotation(1001)
      Real BeamCapacity(1001)
      Real BeamRotation2(10000)
      Real BeamCapacity2(10000)
      Real PeakLoad(10000)

      Common /OutputData/ NumSlabPoints,PeakLoad
      Common /OutputData/ BeamRotation, BeamCapacity
      Common /OutputData/ BeamRotation2,BeamCapacity2
```

```
C       ------------------------------------------------

        Call System("CLS")

        Print*,"THEORETICAL Beam CALCULATIONS"
        Print*," "
        Print*,"ITERATION = ",Iter

        MinRotation=0.000
        MaxRotation=0.2
        DeltaRotation=0.0002

C       ----- Calculate the moment-rotation curve -----

        n = 1
        Rotation = MinRotation
        Do while (Rotation.LE.MaxRotation)
        NumBeamPoints = n
        BeamRotation(n) = Rotation
        Call CalcCapacity(BeamRotation(n),BeamCapacity(n),n)
        n = n + 1
        Rotation = Rotation + DeltaRotation
        End do

        PeakLoad(Iter) = BeamCapacity(1)

C       ----- Pick up a random Rotation and interpolate -----
C       ----- the corresponding moment capacity -----

        IniVar4=IniVar1
        Ix4=int(IniVar4*566927.0)
        Irand4=mod(3612*ix4+5701,566927)
        IniVar4=(real(Irand4)+0.5)/566927.0
        IniVar4=0.2*IniVar4
        BeamRotation2(Iter)=IniVar4
        BeamCapacity2(Iter)= LookUp(IniVar4,NumBeamPoints,
     &              BeamRotation,BeamCapacity)

        End
```

```
C       ------------------------------------------------
            Subroutine CalcCapacity(Rotation,Capacity,NBP)

            Real Deflection
            Real Rotation
            Real Capacity

C       ----- Variables -----

            Real A,B,C,D,E,F,G,H,I,J,K
            Real Length
            Real Scale

C       ----- Iteration Variables -----

            Integer Niter
            Integer Iter
            Common /Iteration/ Niter, Iter

C       ----- Initial Random Variable -----

            Real IniVar1,IniVar2
            Common /RandomData/ Inivar1,IniVar2

C       ----- Declare of Yield Line Data -----

            Integer NumYieldLines
            Real Angle(3,10000)
            Real EndX(3)
            Real EndY(3)

            Common /LineData/ NumYieldLines, Angle
            Common /LineData/ EndX, EndY

C       ----- Beam Data Variables -----

            Real BeamWidth
            Real BeamLength
            Real BeamDepth
```

```
      Integer NumBeamPoints
      Real BeamRota(1001)
      Real BeamMoment(1001)

      Common /BeamData/ BeamWidth, BeamLength, BeamDepth
      Common /BeamData/ NumBeamPoints
      Common /BeamData/ BeamRota, BeamMoment

C     ----- Declare of Slab Variables -----

      Real SlabDiameter
      Real SlabDepth

      Common /SlabData/ SlabDiameter, SlabDepth

C     ----- Other Data -----

      Integer Choice
      Common /OtherData/Choice

C     --------------------------------------------------

      Capacity = 0
      Scale = 1.0
      Scale = Scale*(SlabDepth*SlabDepth)
   &   /(BeamDepth*BeamDepth)

      If (NBP.eq.1) then

      Length=SlabDiameter/2

      If (Choice.eq.1) then
      Capacity = 32.519*Beamwidth*(Length-25)*cos(Angle(1,Iter))
   & /(Scale*3*sqrt(3)*Length)
      End IF

      If (Choice.eq.2) then
      Capacity = 26.057*Beamwidth*(Length-25)*cos(Angle(1,Iter))
   & /(Scale*3*sqrt(3)*Length)
      End IF
```

```
        If (Choice.eq.3) then
        Capacity = 34.030*Beamwidth*(Length-25)*cos(Angle(1,Iter))
     &  /(Scale*3*sqrt(3)*Length)
        End IF

        If (Choice.eq.4) then
        Capacity = 33.023*Beamwidth*(Length-25)*cos(Angle(1,Iter))
     &  /(Scale*3*sqrt(3)*Length)
        End IF

        End If


        If (NBP.gt.1) then


C     ----- Calculate Load Capacities -----


        Length = SlabDiameter/2
        Scale = 1.0
        Scale = Scale * (SlabDepth * SlabDepth)
     &          / (BeamDepth * BeamDepth)


        Deflection=2*(Length-25)*cos(Angle(1,Iter))*tan(0.5*Rotation)
     & /sqrt(3)


        If (Choice.eq.1) then
        A =-68432.475
        B = 80802.856
        C = 47101.177
        D =-39344.928
        E =-13108.115
        F = 8064.5491
        G = 1886.3023
        H =-545.14752
        I =-112.43785
```

```
      J =-12.117675
      K = 1.5417088

      DEF = Deflection + 1.134
      RLoad=A+B*alog(DEF)+C/alog(DEF)+D*(alog(DEF))**2+E/(alog(DEF))**2
  &  +F*(alog(DEF))**3+G/(alog(DEF))**3+H*(alog(DEF))**4
  &  +I/(alog(DEF))**4+J*(alog(DEF))**5+K/(alog(DEF))**5

      End If


      If (Choice.eq.2) then
      A = 73340.247
      B =-74063.356
      C =-35352.874
      D = 53123.006
      E = 14070.326
      F =-20572.549
      G =-3478.8478
      H = 3897.2473
      I = 528.36403
      J =-290.26145
      K =-33.849983

      DEF = Deflection + 1.195
      RLoad=A+B*alog(DEF)+C/alog(DEF)+D*(alog(DEF))**2+E/(alog(DEF))**2
  &  +F*(alog(DEF))**3+G/(alog(DEF))**3+H*(alog(DEF))**4
  &  +I/(alog(DEF))**4+J*(alog(DEF))**5+K/(alog(DEF))**5

      End If


      If (Choice.eq.3) then
      A = 6577.3657
      B = 2964.2754
      C = 5803.3642
      D =-1340.4859
      E =-1277.5013
      F =-174.60146
      G = 187.75212
```

```
      H = 54.28003
      I =-8.952042

      DEF = Deflection + 1.11461
      RLoad=A+B*alog(DEF)+C/alog(DEF)+D*(alog(DEF))**2+E/(alog(DEF))**2
     & +F*(alog(DEF))**3+G/(alog(DEF))**3+H*(alog(DEF))**4
     & +I/(alog(DEF))**4

      End If


      If (Choice.eq.4) then
      A = 4999.969
      B =-12.817587
      C =-69822.675
      D = 37.947642
      E = 376764.74
      F = 56.239729
      G = 133696.3
      H =-35.951185
      I =-49761.358
      J = 8.1246042

      DEF = Deflection + 1.16013
      RLoad=(A+C*(alog(DEF))+E*(alog(DEF))**2+G*(alog(DEF))**3
     & +I*(alog(DEF))**4)/(1+B*(alog(DEF))+D*(alog(DEF))**2
     & +F*(alog(DEF))**3+H*(alog(DEF))**4+J*(alog(DEF))**5)

      End If


C     ----- Calcualte load capacity by virtual work theorem -----


      Capacity = RLoad*beamwidth*Deflection
     & /(1000*Scale*3*Length*Rotation)

      End If

      End
```

```
C      ----------------------
          Subroutine CalcAngle


C      ----- Iteration Variables -----

          Integer Niter
          Integer Iter
          Common /Iteration/ Niter, Iter

C      ----- Initial Random Variable -----

          Real IniVar1,IniVar2
          Common /RandomData/ Inivar1,IniVar2

C      ----- Declare of Yield Line Data -----

          Integer NumYieldLines
          Real Angle(3,10000)
          Real EndX(3)
          Real EndY(3)

          Common /LineData/ NumYieldLines, Angle
          Common /LineData/ EndX, EndY


          PI=3.14159265358979
          Angle(1,Iter+1)=(PI/180)*13.037712*(-alog(IniVar1))**(1/1.108481)
          If (abs(Angle(1,Iter+1)).gt.PI/3) then
          Angle(1,Iter+1)=Angle(1,Iter)
          End If

          End

C      -----------------------------------------------
          Real Function LookUp(Rotation,Size,RotArray,ValArray)

C      ----- Parameters -----
```

```
          Real Rotation
          Integer Size
          Real RotArray(1001)
          Real ValArray(1001)

          Integer n
          Real LowerRot
          Real UpperRot
          Real LowerVal
          Real UpperVal

          n = 1
          Do while ((RotArray(n) < Rotation) .and. (n.LE.Size ))
          n = n + 1
          End do

          If (n .eq. 1) then
          LookUp = ValArray(1)
          End if

          If ((n > 1) .and. (n.LE.Size)) then
          LowerRot = RotArray(n-1)
          UpperRot = RotArray(n)
          LowerVal = ValArray(n-1)
          UpperVal = ValArray(n)
          LookUp = LowerVal + (UpperVal - LowerVal) *
     &     (Rotation - LowerRot) / (UpperRot - LowerRot)
          End If

          If (n > Size) then
          LookUp = ValArray(Size)
          End If

          End

C    --------------------------------------------------
          Subroutine SaveSlabCurve

C    ----- Variables -----
```

```
      Character*(1)  Selection
      Character*(50) FileName

      Print*,"SAVE SLAB RESULTS"
      Print*,"_________________"
      Print*," "
      Print*,"Save the output results ? (y/n) "
      Read*,selection

      If((Selection.eq."y").or.(Selection.eq."Y")) then
      Call GetFileName( FileName )

      Print*," "
      Print*,"Saving to ", FileName, "..."

      Call OutputSlabInfo(FileName)

      Print*," "
      Print*,"Done. "

      End if

      End

C    -------------------------------------------------------
      Subroutine OutputSlabInfo(FileName)

C    ----- Parameters -----

      Character*(50) FileName

      Integer Niter
      Integer Iter
      Common /Iteration/ Niter, Iter

C    ----- Declare of Slab Variables -----

      Real SlabDiameter
      Real SlabDepth
```

```
      Common /SlabData/ SlabDiameter, SlabDepth

C     ----- Declare of Yield Line Data -----

      Integer NumYieldLines
      Real Angle(3,10000)
      Real EndX(3)
      Real EndY(3)

      Common /LineData/ NumYieldLines, Angle
      Common /LineData/ EndX, EndY

C     ----- Output Data -----

      Integer NumSlabPoints

      Real BeamRotation(1001)
      Real BeamCapacity(1001)
      Real BeamRotation2(10000)
      Real BeamCapacity2(10000)
      Real PeakLoad(10000)

      Common /OutputData/ NumSlabPoints,PeakLoad
      Common /OutputData/ BeamRotation, BeamCapacity
      Common /OutputData/ BeamRotation2,BeamCapacity2

C     ----- Variables -----

      Integer n,m

C     ------------------------------------------------------------

      Open(Unit=1, File=FileName, Status='NEW')

      Write(Unit=1, Fmt=610) SlabDiameter, SlabDepth
 610  Format(F10.4, T12, F10.4)

      Write(Unit=1, Fmt=620) NumYieldLines
 620  Format(I10)
```

```
      n = 1
      Do while (n.le.Niter)
      Write(Unit=1, Fmt=630) (Angle(m,n), m=1,3)
630   Format( T12, 3 F12.8 )
      n = n + 1
      End do

      Write(Unit=1, Fmt=640) NumSlabPoints
640   Format(I10)

      n = 1
      Do while (n.le.Niter)
      Write(Unit=1, Fmt=650) BeamRotation2(n),
     &        BeamCapacity2(n),PeakLoad(n)
650   Format(F10.6, T12, F12.4, F12.4)
      n = n + 1
      End Do

      EndFile(Unit=1)
      Close(Unit =1)

      End
```

1.3. Example for the program MCSRDP2

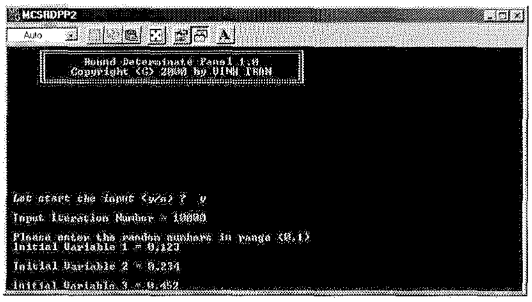


Figure 1 – Input iteration and initial random numbers.

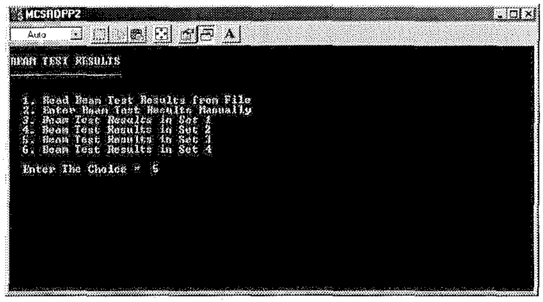


Figure 2 – Select the data of beam test

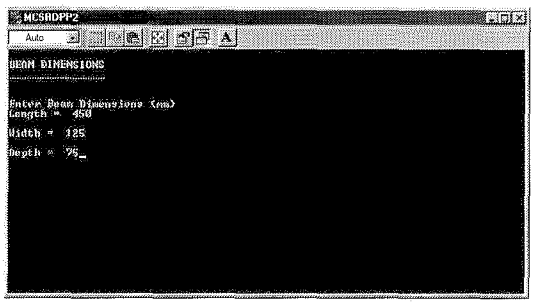


Figure 3 – Input beam dimesions

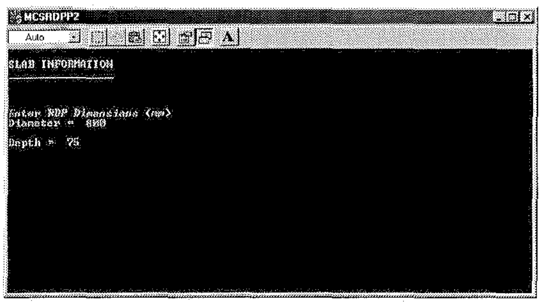


Figure 4 – Input slab dimesions

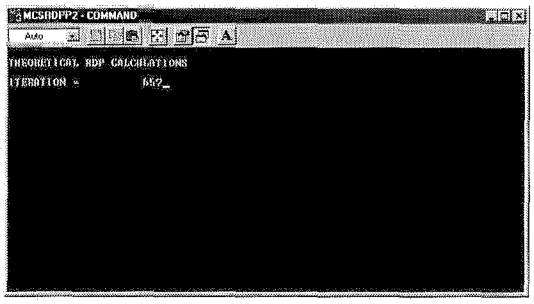


Figure 5 – The proram is running calculation for each iteration

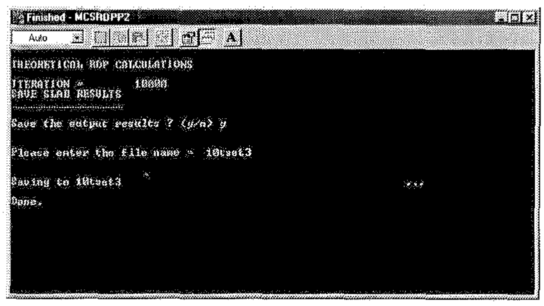


Figure 6 – Save the results for output

Input:

Iteration Number = 10,000

Initial Variables 1 = 0.123
Initial Variables 2 = 0.234
Initial Variables 3 = 0.452

Beam test of concrete set 3

Beam dimension:
Length = 450mm

Width = 125mm
Depth = 75mm

Slab dimension:
Diameter = 800mm
Thickness= 75mm

Output

Diameter Thickness
800 75
Number of yield lines
3

	Crack Angles (radian)		
Iteration No.	Angle 1	Angle 2	Angle 3
1	0.443544	0.318648	0.184816
2	0.278703	-0.33793	-0.11421
3	-0.07058	0.162417	0.455667
4	0.14382	0.473771	-0.02554
5	-0.10737	0.783985	-0.72313
6	-0.58284	-0.30868	-0.18513
7	-0.06417	0.063353	0.362192
8	-0.05361	0.111427	0.317159
9	0.386774	-0.05924	0.125551
10	-0.05145	0.287573	-0.29121
11	-0.05975	0.576488	-0.303
12	0.523161	-0.39312	-0.14311
.			
.			
.			
9984	0.682818	-0.40368	-0.14902
9985	-0.02695	0.046207	0.198174
9986	0.485316	-0.04514	0.11509
9987	-0.12442	0.390059	-0.42093
9988	0.20425	-0.06168	0.011601
9989	-0.1484	0.080085	0.480626
9990	0.008754	0.005985	0.142769
9991	-0.08264	0.14439	0.260857
9992	-0.06381	0.198721	-0.21758
9993	0.397433	-0.12003	0.067212
9994	-0.04661	0.461689	-0.17662
9995	-0.04739	0.022934	0.172144
9996	0.407629	-0.61549	-0.05816
9997	-0.06787	0.169542	-0.19216
9998	-0.08865	0.317928	-0.21938
9999	0.015841	0.27183	-0.10946
10000	-0.16052	0.10001	0.338295

Iteration No.	Deflection (mm)	Load (N)	Cracking Load (N)
1	4.616926	9413.206	33402.13
2	36.61152	2725.926	32523.53
3	1.090193	11468.36	32770.82
4	18.05294	4762.782	32850.61
5	7.499766	8887.083	36936.51
6	9.430667	7207.576	34177.88
7	23.84564	3862.171	32279.1
8	10.7447	6548.359	32146.99
9	10.12783	6769.197	32418.31
10	21.99504	4102.618	32357.17
11	6.34632	8330.528	33799.56
12	3.181679	10153.06	33804.58
.			
.			
.			
9986	38.55032	2617.109	32885.66
9987	4.048105	9570.311	33149.23
9988	22.02996	4101.093	31793.85
9989	12.49589	6026.585	32867.66
9990	15.4459	5268.322	31669.46
9991	30.87999	3139.72	32040.71
9992	18.79815	4603.666	31999.57
9993	19.20039	4541.423	32448.15
9994	32.0867	3031.208	32878.07
9995	17.4571	4853.129	31726.12
9996	15.31157	5334.103	34090.6
9997	25.65011	3644.066	31904.48
9998	8.472731	7330.978	32345.47
9999	3.779428	9556.649	31991.45
10000	11.5702	6282.854	32283.33

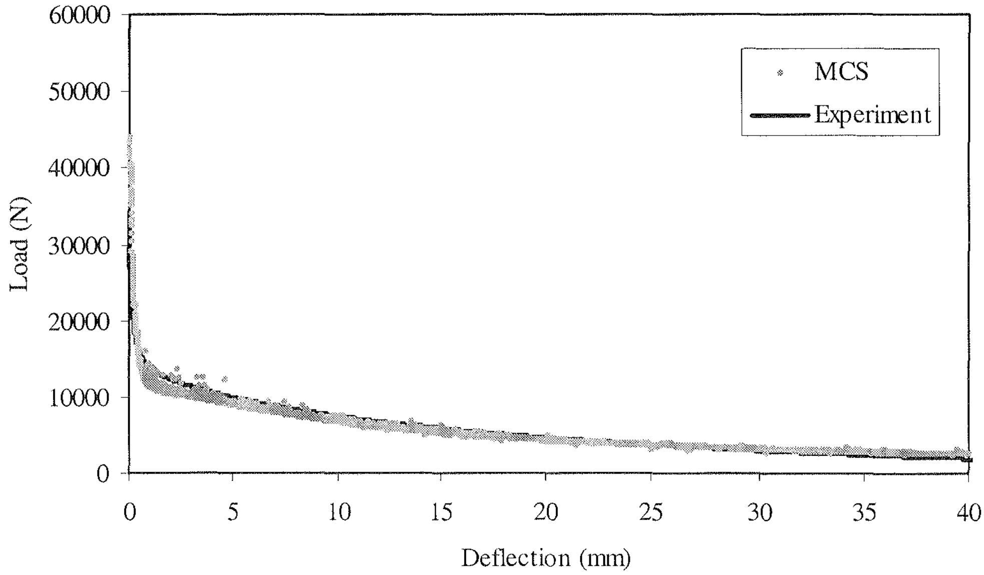


Figure 7 – Post-craking load-deflection relationship of RD panel.

2. EXPERIMENTAL RESULTS

This part is to attach the result sheets of experimental results of fibre reinforced shotcrete beam and panel specimen for four sets of concrete (see Chapter 3 in Volume 1). On the following pages, the performance of the specimens in the centrally load beam tests and RD panel tests are summarised. These experimental programs and data processing have been done by the author at the University of Western Sydney.

2.1. Experimental Results of the Beam Tests

2.1.1. Concrete Set 1

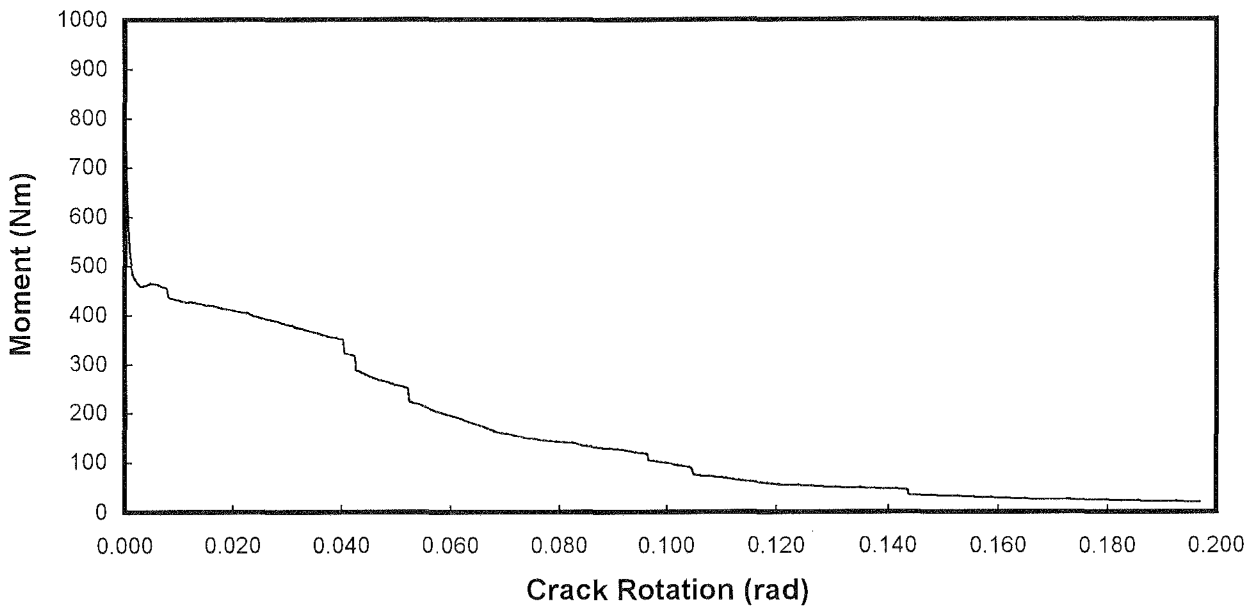
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 19-Jan-01

Specimen: Vinh Crack Rotation Beam V1-C01 **Age:** 91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	76.0	126.0	4	26	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	77.8	128.7	0	19	**Section Modulus**	
Value 3	78.9	125.2				
Mean	77.6	126.6	2.0	22.5	126983 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

2.62 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 19.49 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

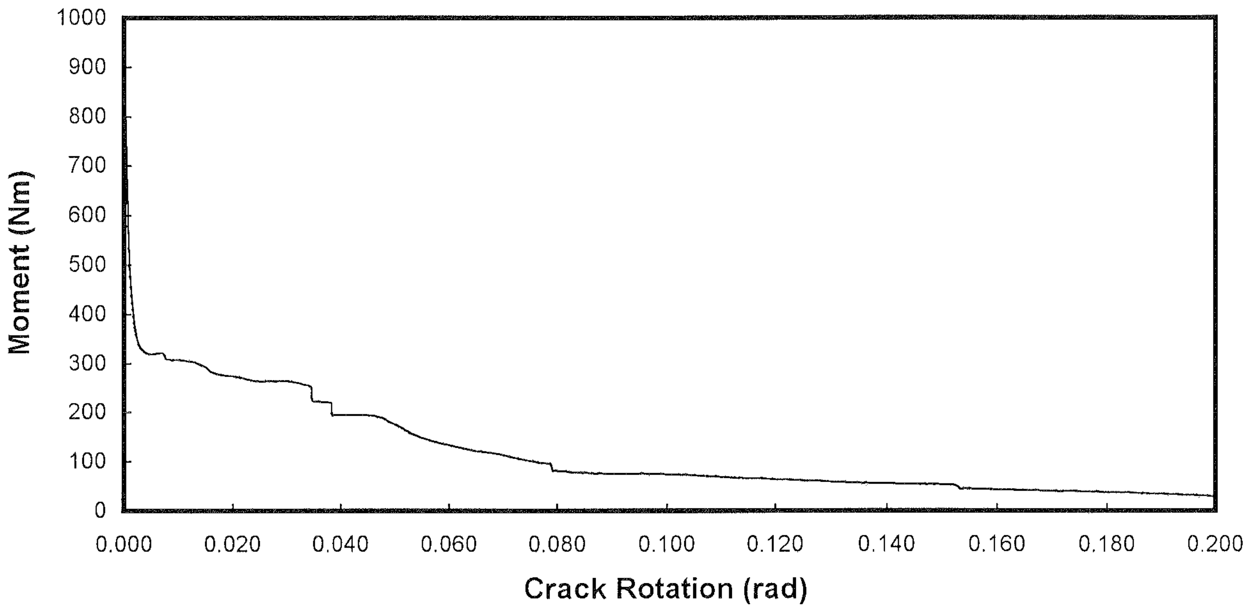
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 19-Jan-01

Specimen: Vinh Crack Rotation Beam V1-C02 **Age:** 91 days



Dimensional Data
(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span		Measurement and Calculation of Results
Value 1	75.2	125.9	0	23	450	mm	Depth and width are measured adjacent to the crack after
Value 2	76.4	124.9	-9	10	**Section**		completion of test. Very few tests produce more than one
Value 3	75.8	124.0			**Modulus**		crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	75.8	124.9	-4.5	16.5	119637	mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 44 mm Lever arm to Strain 2 40 mm

Flexural Strength

8.01 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 19.49 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

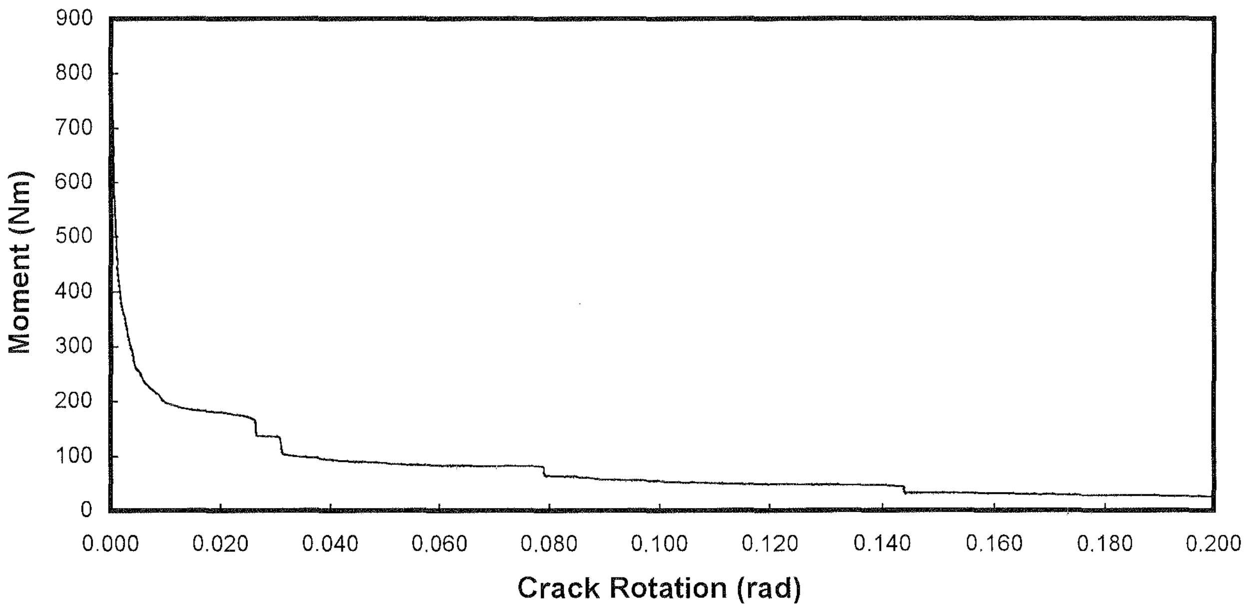
The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client:	Comparative Beam and Panel Tests	Date:	19-Jan-01
Specimen:	Vinh Crack Rotation Beam V1-C03	Age:	91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	78.2	124.9	0	14	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	78.0	126.1	2	13	**Section Modulus**	
Value 3	77.1	125.0				
Mean	77.8	125.3	1.0	13.5	126329 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

6.58 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 8.56 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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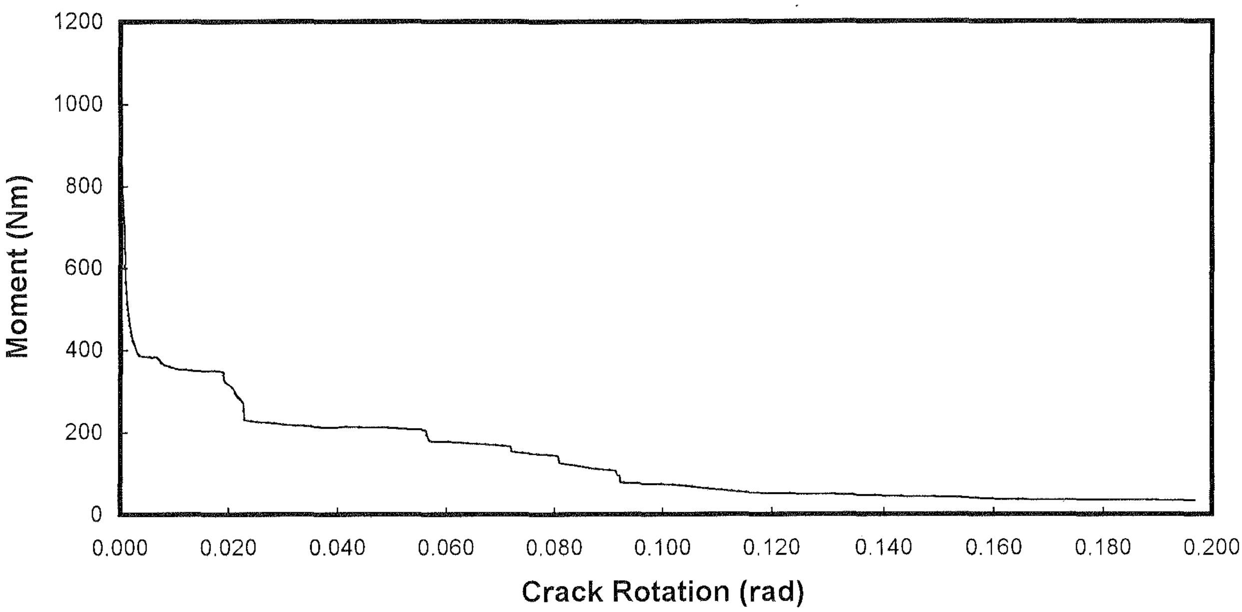
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 19-Jan-01

Specimen: Vinh Crack Rotation Beam V1-C04 **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span		Measurement and Calculation of Results
Value 1	75.8	130.2	1	21	450	mm	Depth and width are measured adjacent to the crack after
Value 2	75.9	123.9	0	10	Section		completion of test. Very few tests produce more than one
Value 3	78.1	124.0			Modulus		crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	76.6	126.0	0.5	15.5	123251	mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 41 mm Lever arm to Strain 2 43 mm

Flexural Strength

7.82 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 14.54 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

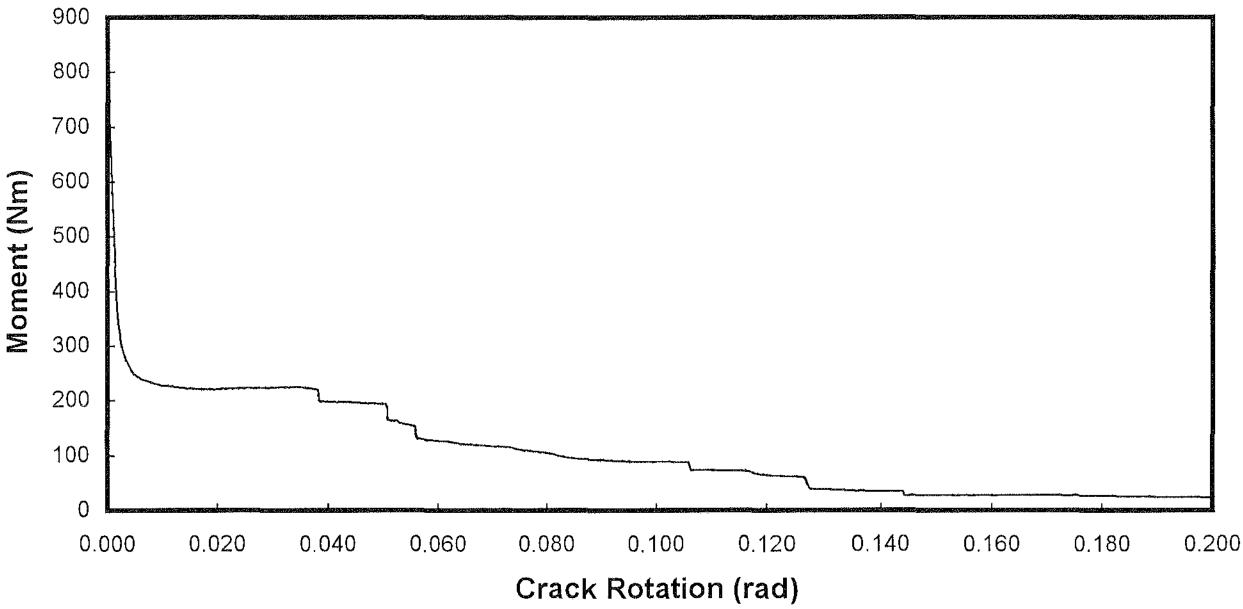
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 19-Jan-01

Specimen: Vinh Crack Rotation Beam V1-C05 **Age:** 91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span		Measurement and Calculation of Results
Value 1	74.1	129.2	0	18	450	mm	Depth and width are measured adjacent to the crack after
Value 2	76.4	125.0	-8	13	Section		completion of test. Very few tests produce more than one
Value 3	78.0	125.9			Modulus		crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	76.2	126.7	-4.0	15.5	122505	mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 43 mm Lever arm to Strain 2 41 mm

Flexural Strength

7.05 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 11.79 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

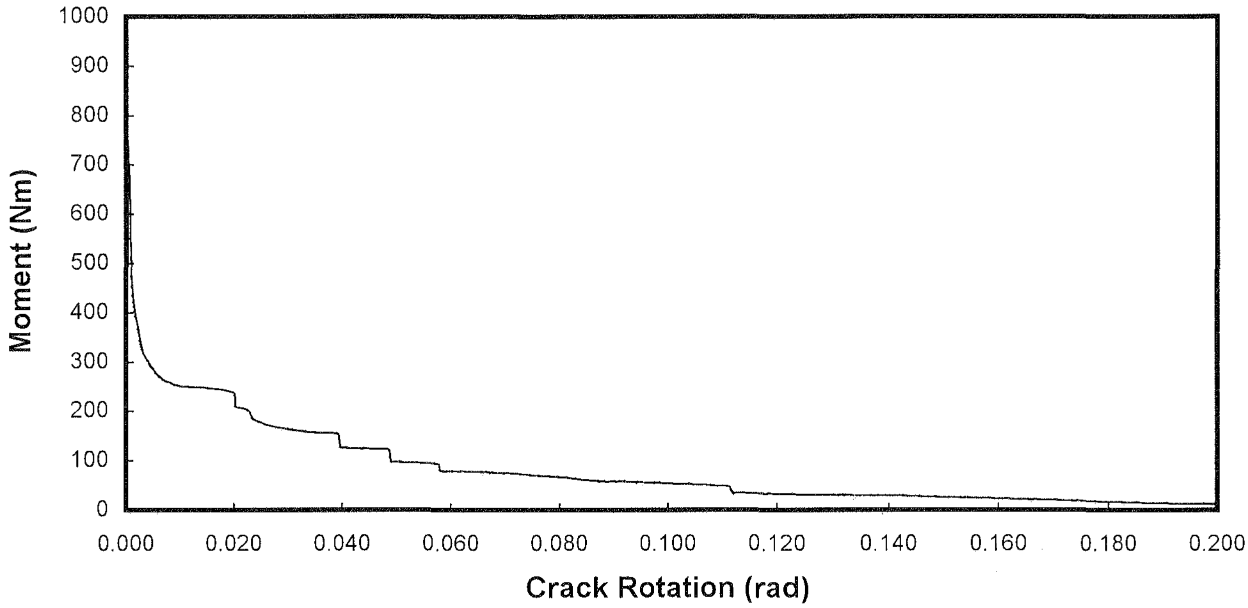
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 19-Jan-01

Specimen: Vinh Crack Rotation Beam V1-C07 **Age:** 91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	76.8	124.0	0	19	450 mm	Depth and width are measured adjacent to the crack after
Value 2	75.2	124.1	11	14	**Section**	completion of test. Very few tests produce more than one
Value 3	74.1	128.7			**Modulus**	crack. Section Modulus is calculated as Z=bd^2/6, and is
Mean	75.4	125.6	5.5	16.5	118904 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.50 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 10.50 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

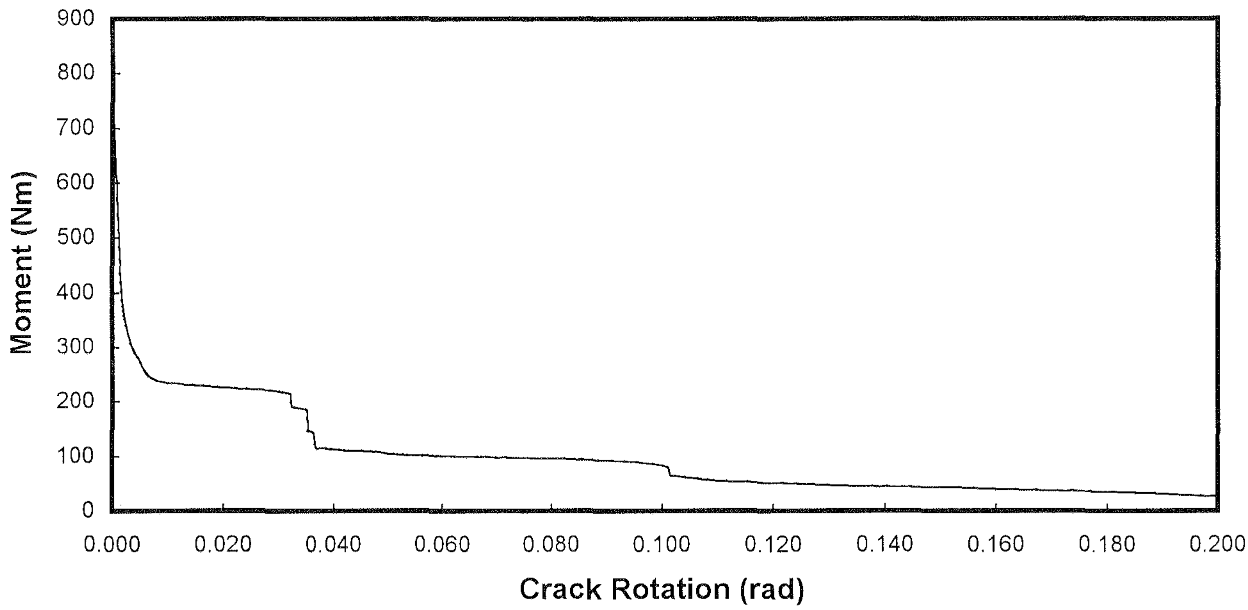
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 19-Jan-01

Specimen: Vinh Crack Rotation Beam V1-C08 **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	76.9	125.3	-12	16	450 mm	Depth and width are measured adjacent to the crack after
Value 2	74.9	125.7	-11	15	**Section**	completion of test. Very few tests produce more than one
Value 3	76.8	125.6			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	76.2	125.5	-11.5	15.5	121484 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.37 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 10.63 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

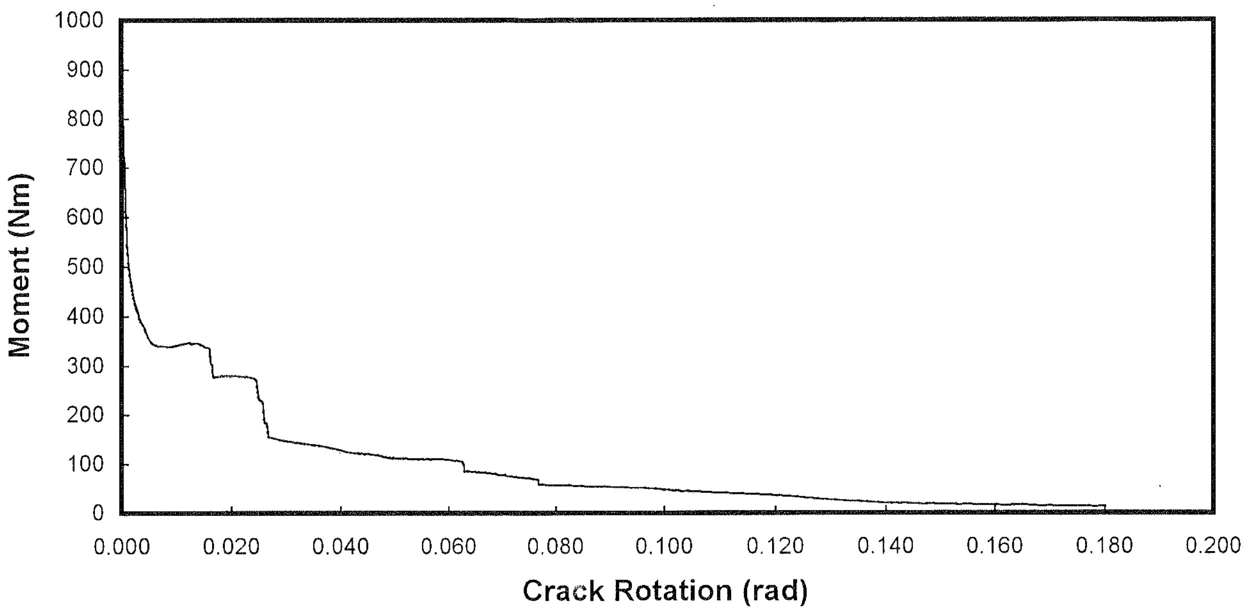
The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client:	Comparative Beam and Panel Tests	Date:	19-Jan-01
Specimen:	Vinh Crack Rotation Beam V1-C09	Age:	91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	78.0	126.5	28	19	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	77.3	127.0	14	11	**Section Modulus**	
Value 3	77.0	129.0				
Mean	77.4	127.5	21.0	15.0	127413 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.50 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 12.15 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

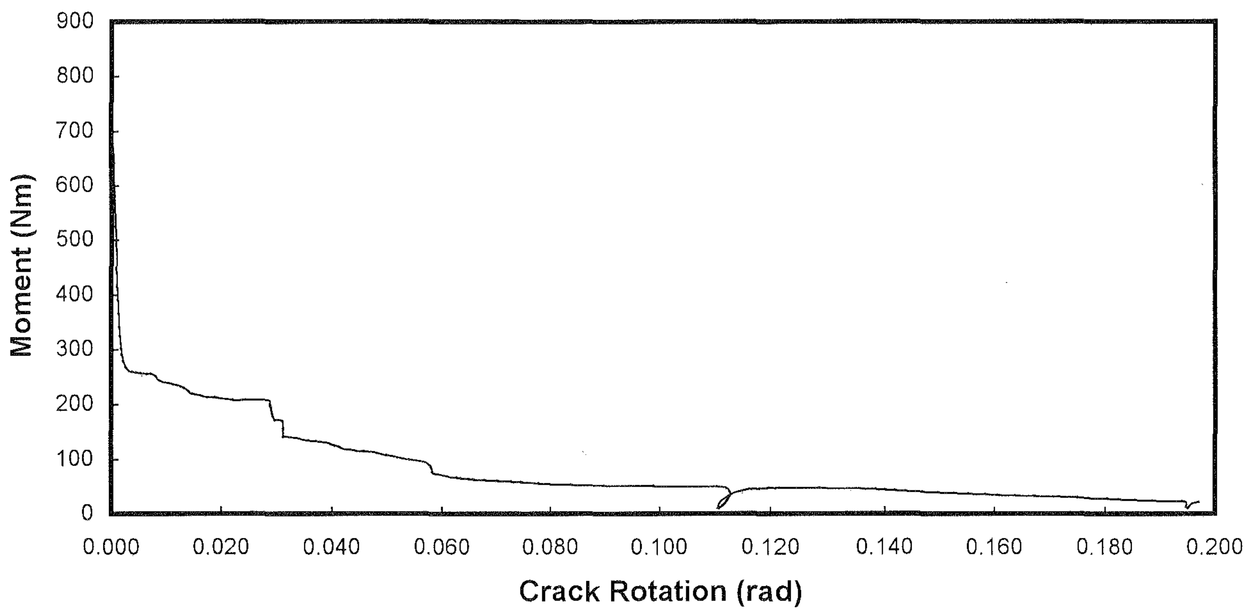
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 19-Jan-01

Specimen: Vinh Crack Rotation Beam V1-C10 **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span
Value 1	76.0	127.2	23	21	450 mm
Value 2	78.0	124.9	27	13	**Section**
Value 3	76.2	124.5			**Modulus**
Mean	76.7	125.5	25.0	17.0	123190 mm^3

Measurement and Calculation of Results

Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

6.31 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 9.94 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

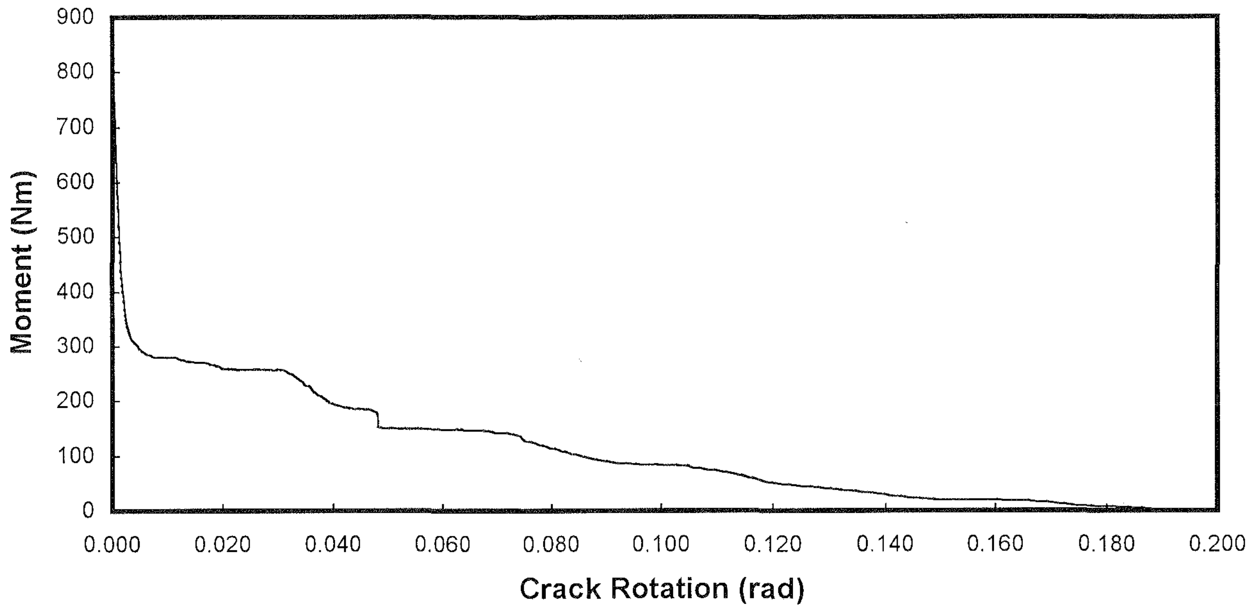
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 19-Jan-01

Specimen: Vinh Crack Rotation Beam V1-C11 **Age:** 91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	76.9	126.0	27	15	450 mm	Depth and width are measured adjacent to the crack after
Value 2	77.0	125.1	24	12	**Section**	completion of test. Very few tests produce more than one
Value 3	76.8	125.3			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	76.9	125.5	25.5	13.5	123660 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

6.84 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 12.98 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

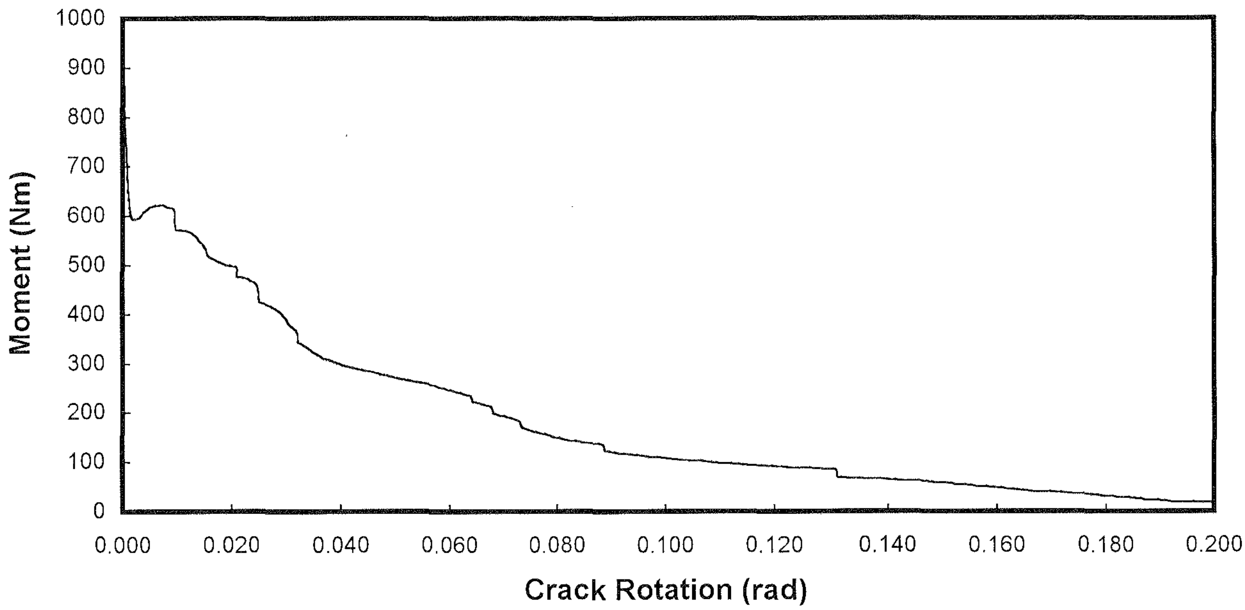
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: **Comparative Beam and Panel Tests** **Date: 19-Jan-01**

Specimen: **Vinh Crack Rotation Beam V1-C12** **Age: 91 days**



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	77.2	128.0	18	15	450 mm	Depth and width are measured adjacent to the crack after
Value 2	75.8	126.7	0	14	**Section**	completion of test. Very few tests produce more than one
Value 3	74.3	126.1			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	75.8	126.9	9.0	14.5	121445 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 43 mm Lever arm to Strain 2 41 mm

Flexural Strength

7.88 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 22.26 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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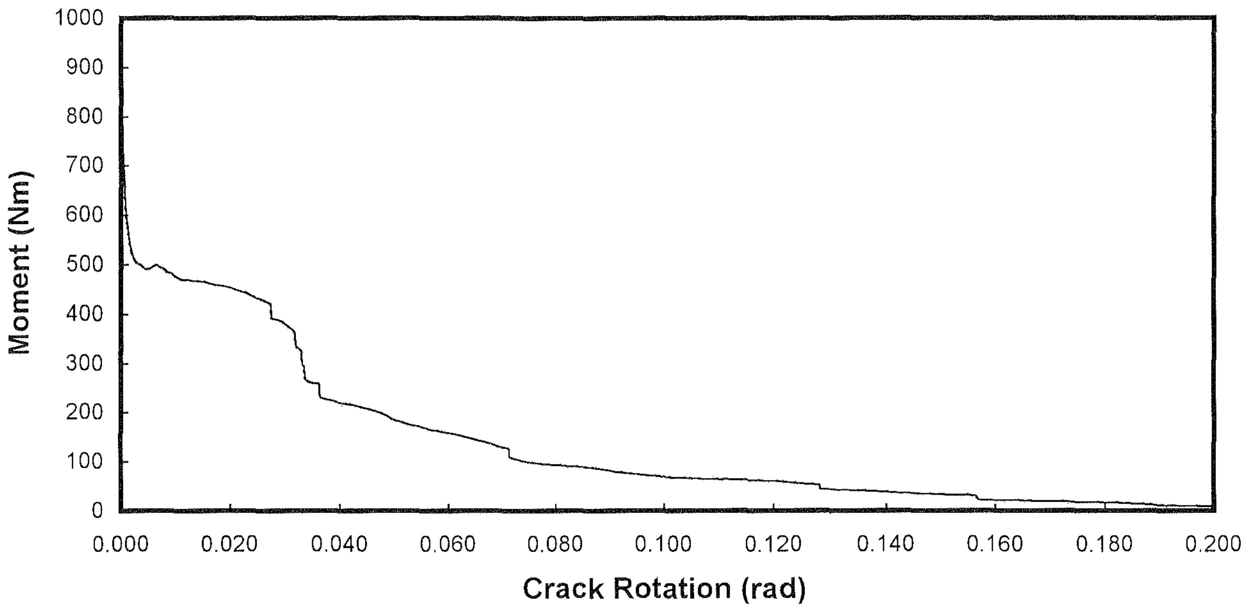
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 19-Jan-01

Specimen: Vinh Crack Rotation Beam V1-C13 **Age:** 91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	77.0	124.0	0	16	450 mm	Depth and width are measured adjacent to the crack after
Value 2	76.9	124.6	0	15	**Section**	completion of test. Very few tests produce more than one
Value 3	78.1	127.0			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	77.3	125.2	0.0	15.5	124792 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 44 mm Lever arm to Strain 2 40 mm

Flexural Strength

7.20 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 19.00 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

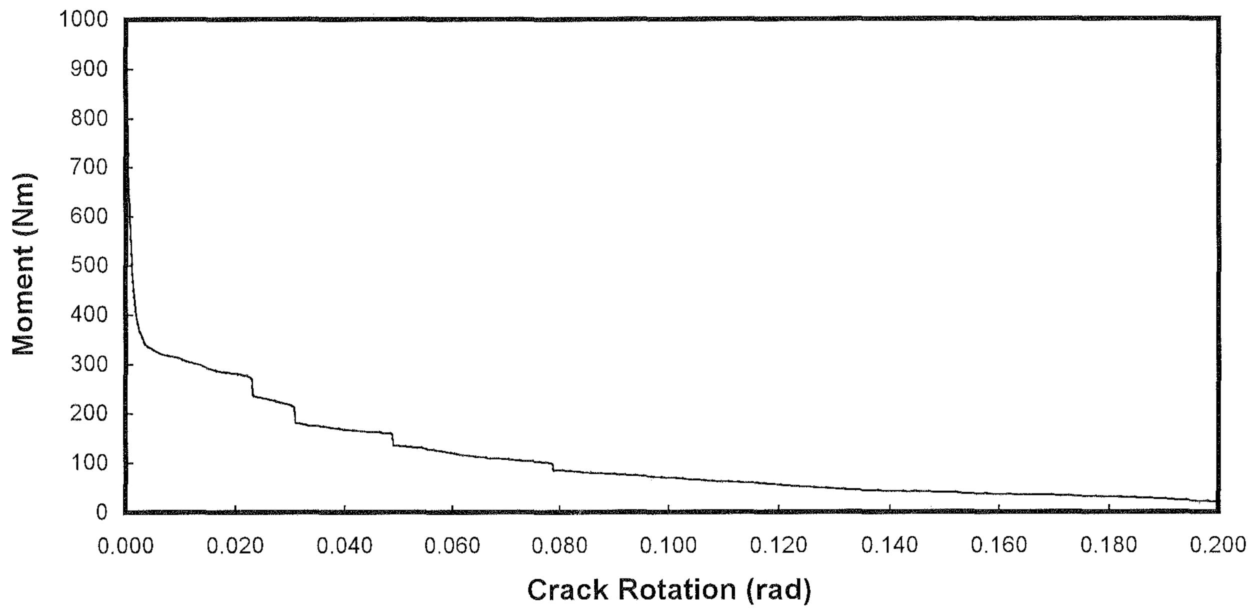
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests — **Date:** 19-Jan-01

Specimen: Vinh Crack Rotation Beam V1-C14 — **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span		Measurement and Calculation of Results
Value 1	73.2	128.0	-7	20	450	mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	75.9	128.2	-7	12	**Section Modulus**		
Value 3	77.4	129.3					
Mean	75.5	128.5	-7.0	16.0	122080	mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

8.14 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 12.64 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

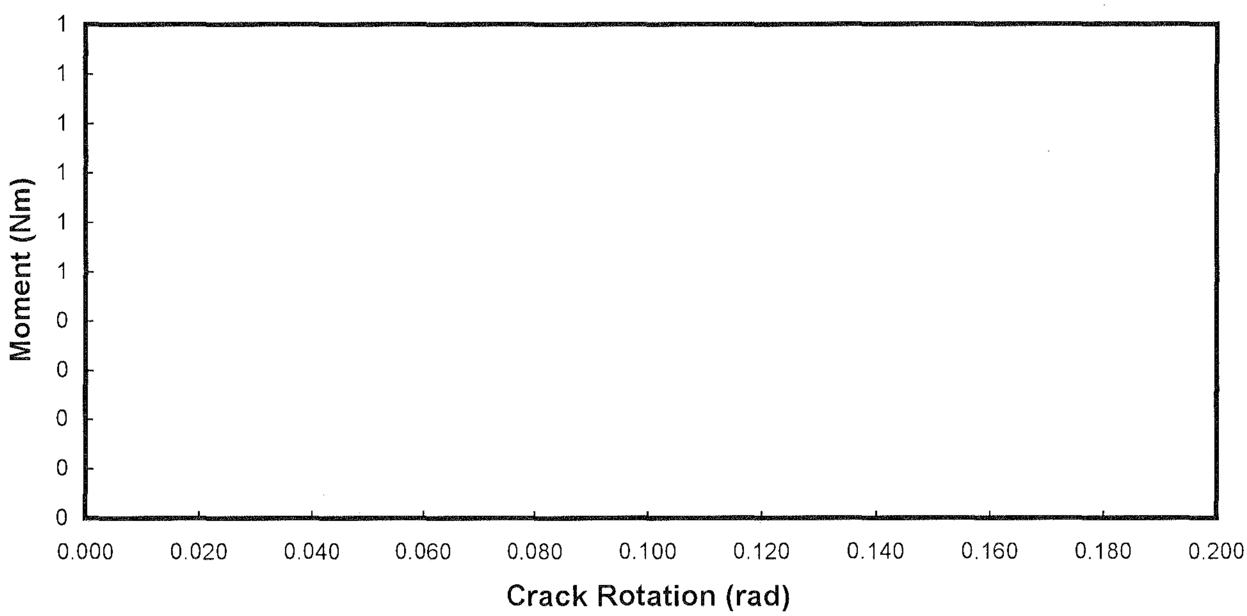
The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client:	**Comparative Beam and Panel Tests**	**Date:**	**19-Jan-01**
Specimen:	**Vinh Crack Rotation Beam V1-C15**	**Age:**	**91 days**



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span		Measurement and Calculation of Results
Value 1	76.9	126.0	-12	18	450	mm	Depth and width are measured adjacent to the crack after
Value 2	77.4	125.0	-7	16	**Section**		completion of test. Very few tests produce more than one
Value 3	77.2	124.8			**Modulus**		crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	77.2	125.3	-9.5	17.0	124321	mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 43 mm Lever arm to Strain 2 41 mm

Flexural Strength

0.00 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 12.64 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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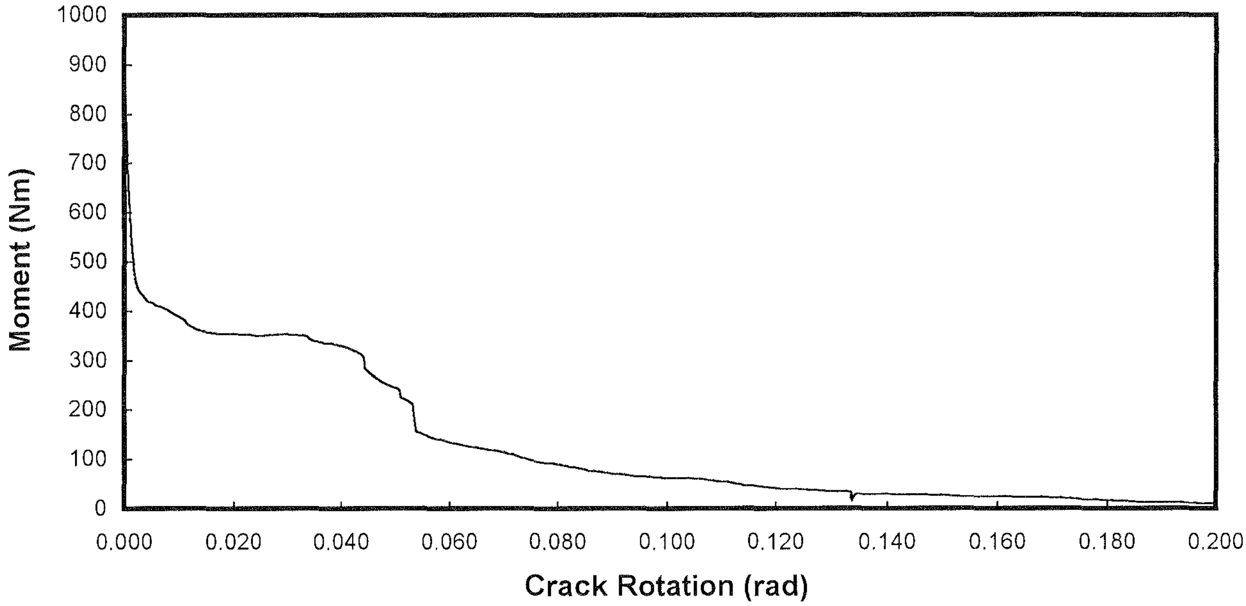
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests | **Date:** 19-Jan-01

Specimen: Vinh Crack Rotation Beam V1-C16 | **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	74.0	126.8	0	18	450 mm	Depth and width are measured adjacent to the crack after
Value 2	74.8	126.9	0	18	**Section**	completion of test. Very few tests produce more than one
Value 3	75.0	123.9			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	74.6	125.9	0.0	18.0	116745 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

0.23 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 17.45 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

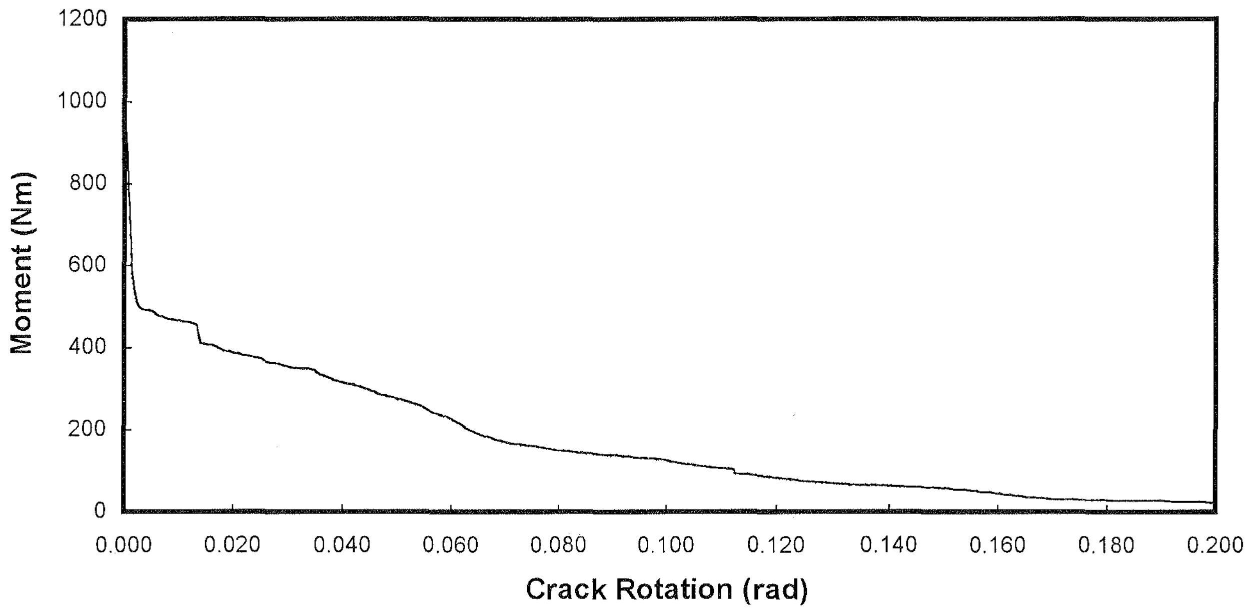
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 19-Jan-01

Specimen: Vinh Crack Rotation Beam V1-C17 **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	76.4	124.2	6	21	450 mm	Depth and width are measured adjacent to the crack after
Value 2	78.0	123.0	2	15	**Section**	completion of test. Very few tests produce more than one
Value 3	77.1	125.1			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	77.2	124.1	4.0	18.0	123163 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.85 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 19.78 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

2.1.2. Concrete Set 2

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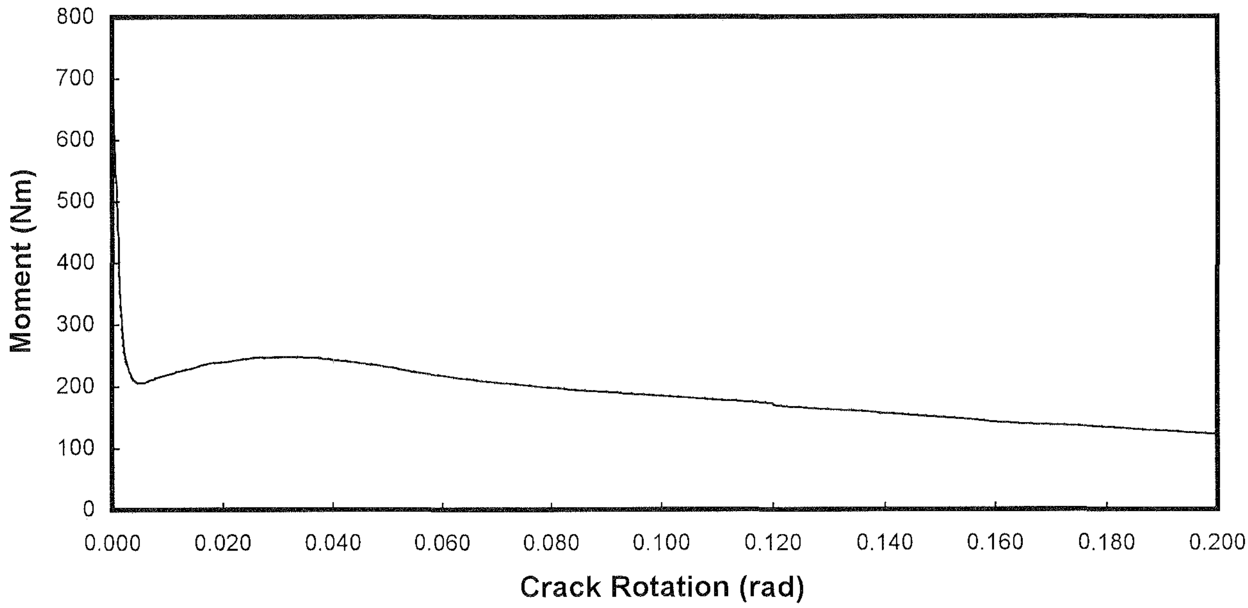
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: **Comparative Beam and Panel Tests** **Date: 5-Jan-01**

Specimen: **Vinh Crack Rotation Beam V2-C01** **Age: 91 days**



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span		Measurement and Calculation of Results
Value 1	74.2	124.5	32	57	450	mm	Depth and width are measured adjacent to the crack after
Value 2	74.7	124.3	7	57	**Section**		completion of test. Very few tests produce more than one
Value 3	75.4	127.1			**Modulus**		crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	74.8	125.3	19.5	57.0	116739	mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

5.76 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 12.25 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

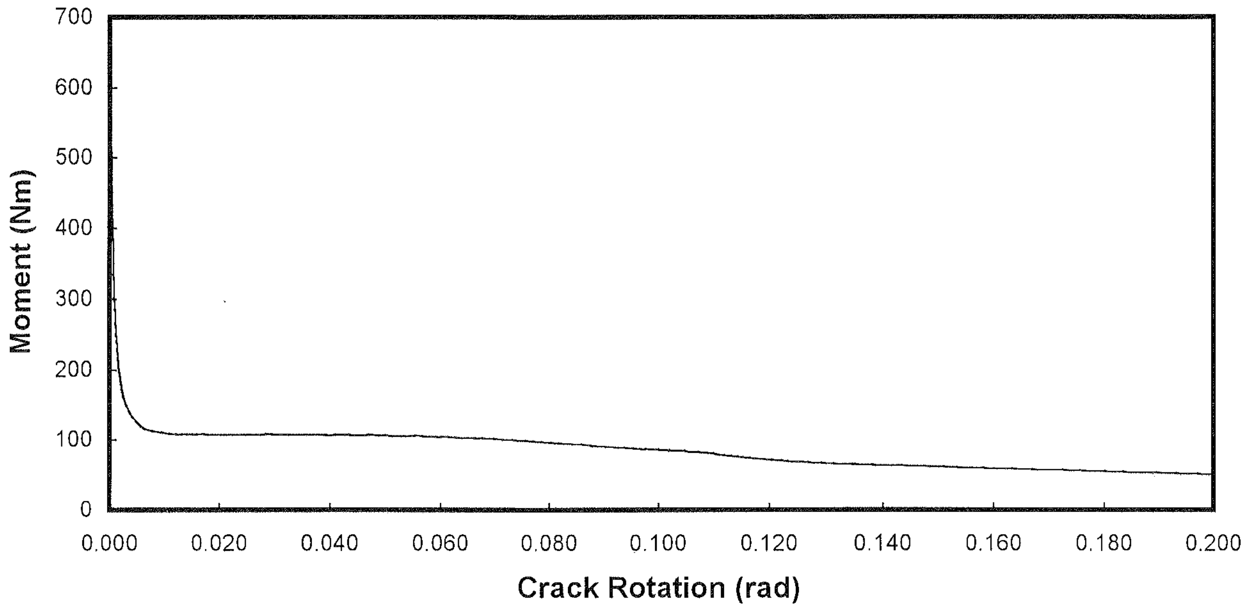
Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney, Nepean
Civic Engineering and Environment
Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 5-Jan-01
Specimen: Vinh Crack Rotation Beam V2-C02 **Age:** 91 days



Dimensional Data
(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	74.0	125.1	20	50	450 mm	Depth and width are measured adjacent to the crack after
Value 2	74.9	126.0	0	43	**Section**	completion of test. Very few tests produce more than one
Value 3	73.1	126.0			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	74.0	125.7	10.0	46.5	114722 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

5.40 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 5.97 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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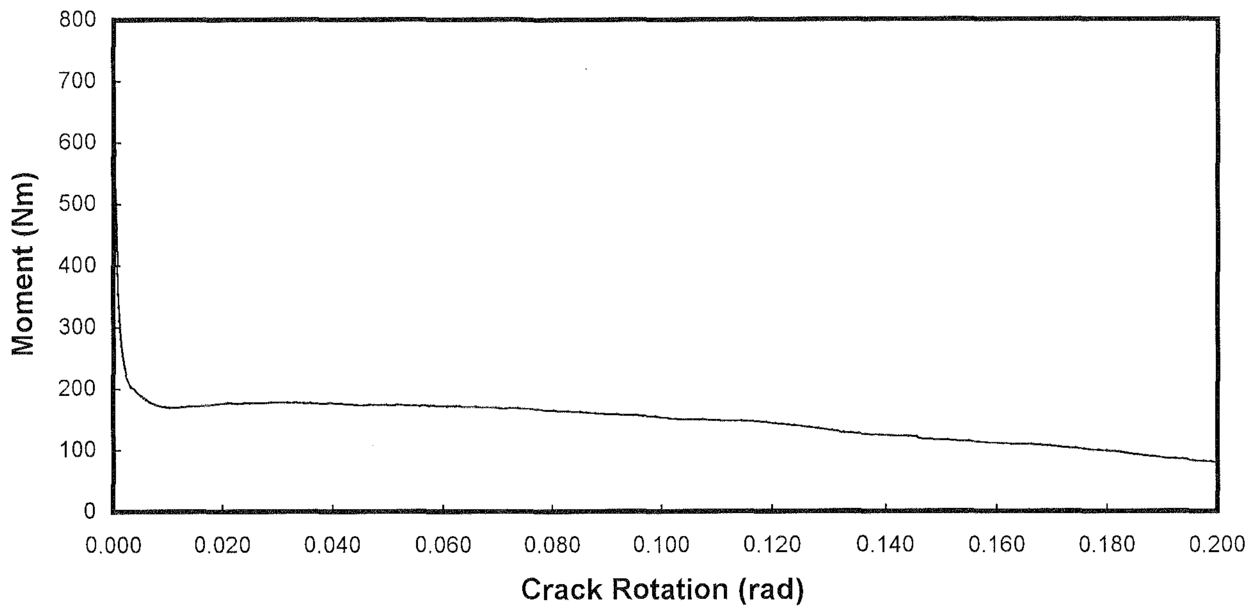
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests — **Date:** 5-Jan-01

Specimen: Vinh Crack Rotation Beam V2-C03 — **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	
Value 1	76.5	124.1	6	57	450	mm
Value 2	77.2	125.2	-4	35	**Section Modulus**	
Value 3	75.9	125.4				
Mean	76.5	124.9	1.0	46.0	121931	mm^3

Measurement and Calculation of Results

Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

5.53 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 9.25 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

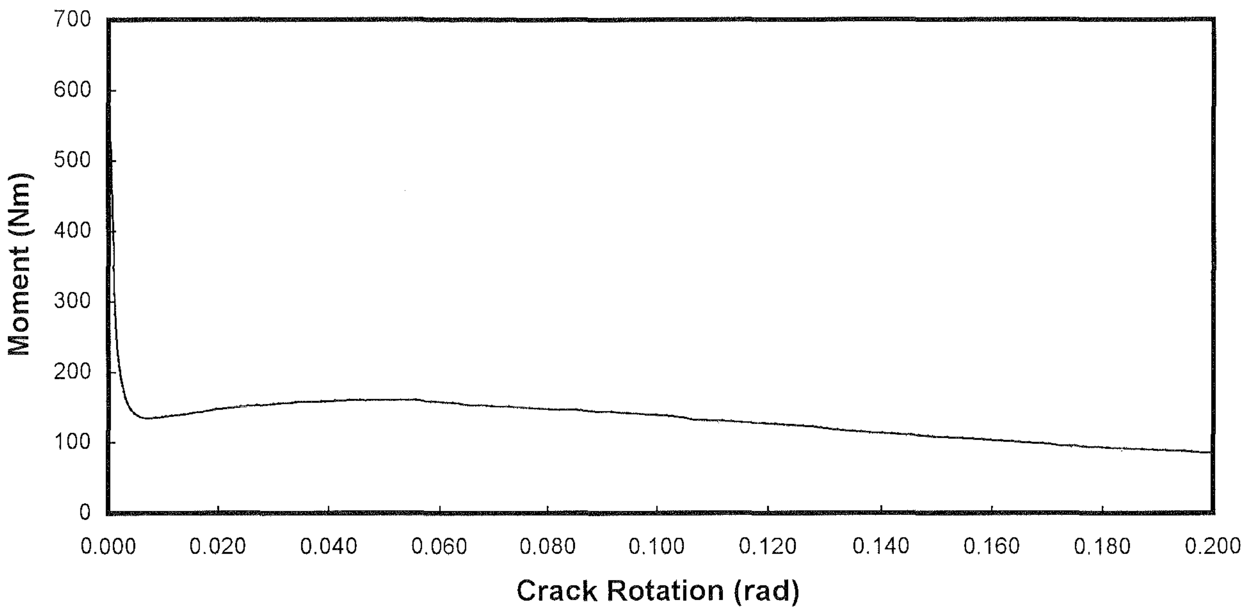
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: **Comparative Beam and Panel Tests** Date: **5-Jan-01**

Specimen: **Vinh Crack Rotation Beam V2-C04** Age: **91 days**



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span		Measurement and Calculation of Results
Value 1	75.6	125.0	22	56	450	mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	75.3	125.1	28	42	**Section Modulus**		
Value 3	75.3	125.3					
Mean	75.4	125.1	25.0	49.0	118567	mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

5.42 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 8.02 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

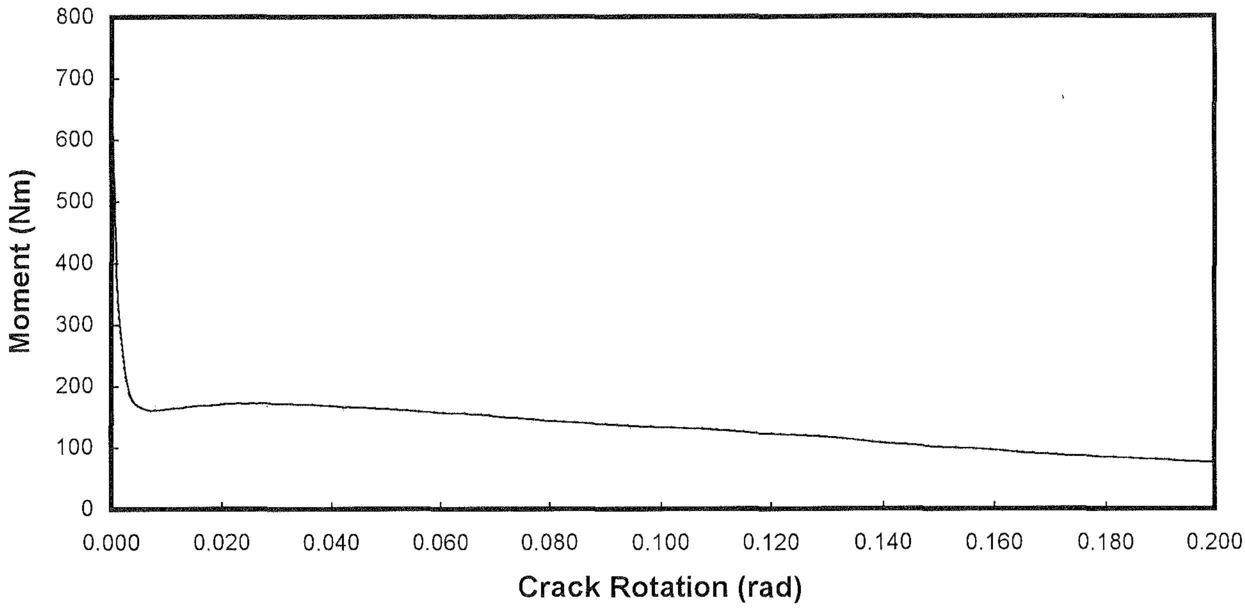
The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client:	Comparative Beam and Panel Tests	Date:	5-Jan-01
Specimen:	Vinh Crack Rotation Beam V2-C05	Age:	91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	74.8	125.6	0	43	450 mm	Depth and width are measured adjacent to the crack after
Value 2	74.4	125.7	11	52	Section	completion of test. Very few tests produce more than one
Value 3	76.2	127.3			Modulus	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	75.1	126.2	5.5	47.5	118734 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

5.78 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 4.98 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

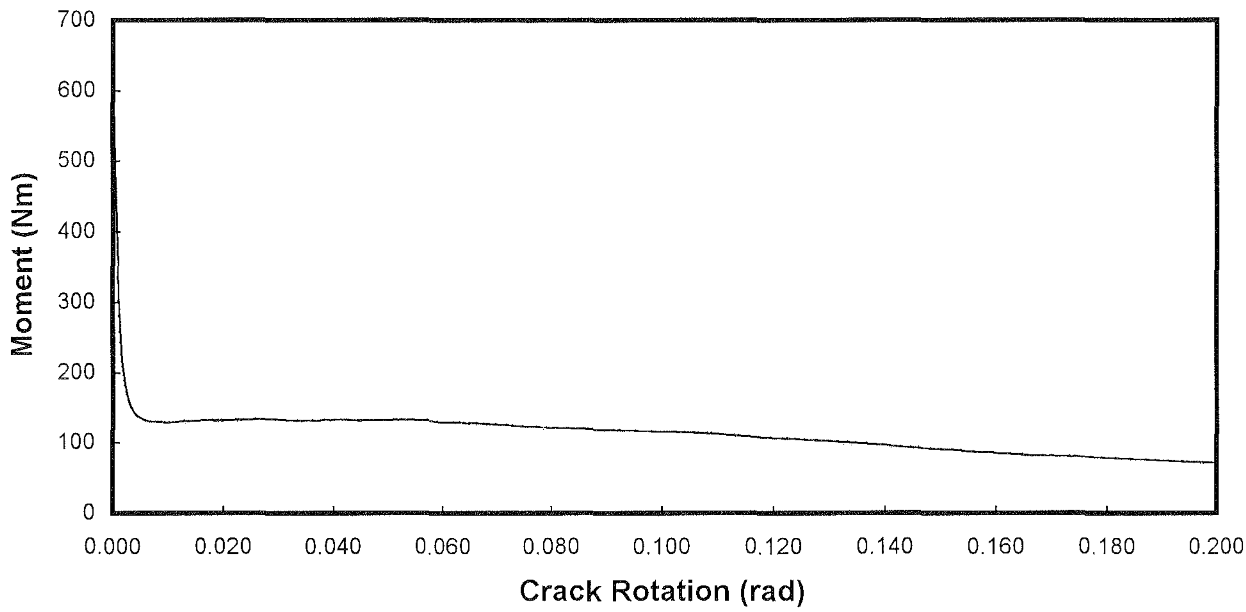
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests — **Date:** 5-Jan-01

Specimen: Vinh Crack Rotation Beam V2-C06 — **Age:** 107 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	75.7	122.8	6	50	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	75.6	123.3	4	44	**Section Modulus**	
Value 3	76.1	123.7				
Mean	75.8	123.3	5.0	47.0	118041 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

5.34 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 7.14 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

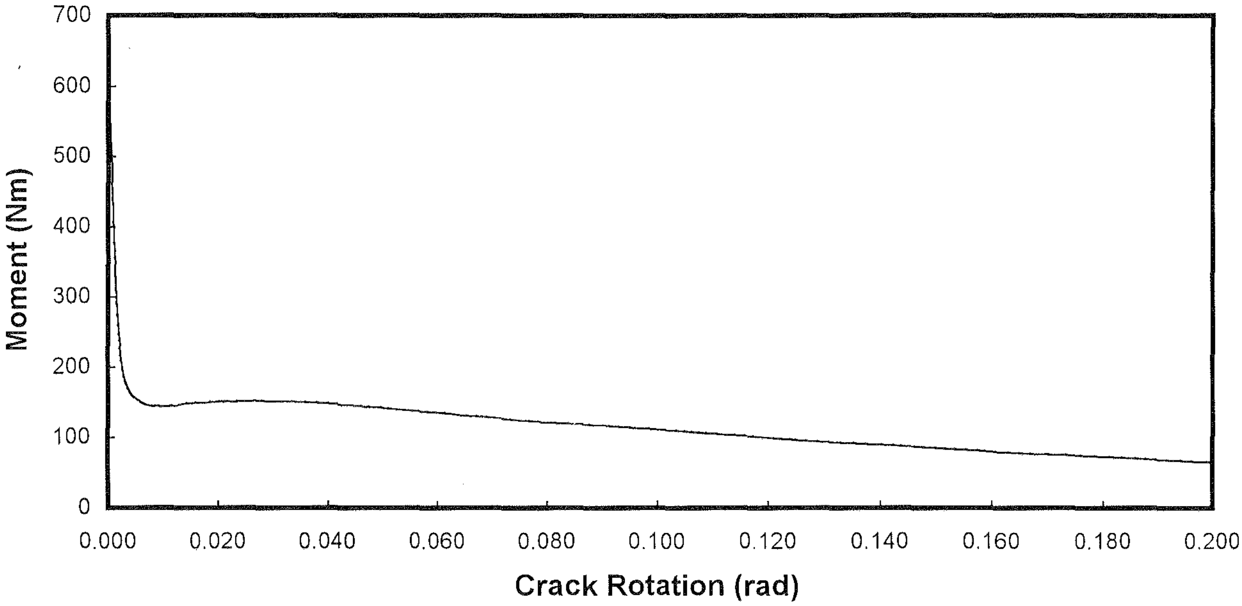
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 5-Jan-01

Specimen: Vinh Crack Rotation Beam V2-C07 **Age:** 107 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	76.5	126.8	22	52	450 mm	Depth and width are measured adjacent to the crack after
Value 2	75.5	127.5	22	42	**Section**	completion of test. Very few tests produce more than one
Value 3	75.9	127.2			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	76.0	127.2	22.0	47.0	122312 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

5.08 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 8.05 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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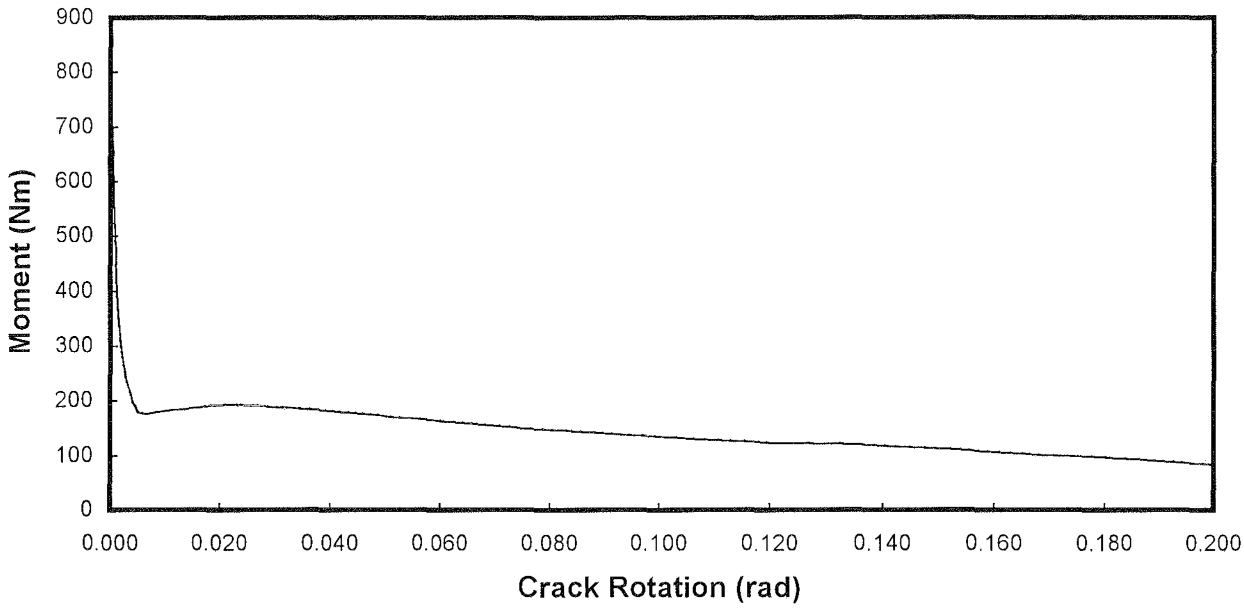
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: **Comparative Beam and Panel Tests** Date: **5-Jan-01**

Specimen: **Vinh Crack Rotation Beam V2-C08** Age: **107 days**



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	79.6	124.5	-11	49	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	80.5	122.9	-5	44	**Section Modulus**	
Value 3	80.8	126.1				
Mean	80.3	124.5	-8.0	46.5	133798 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

6.18 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 9.94 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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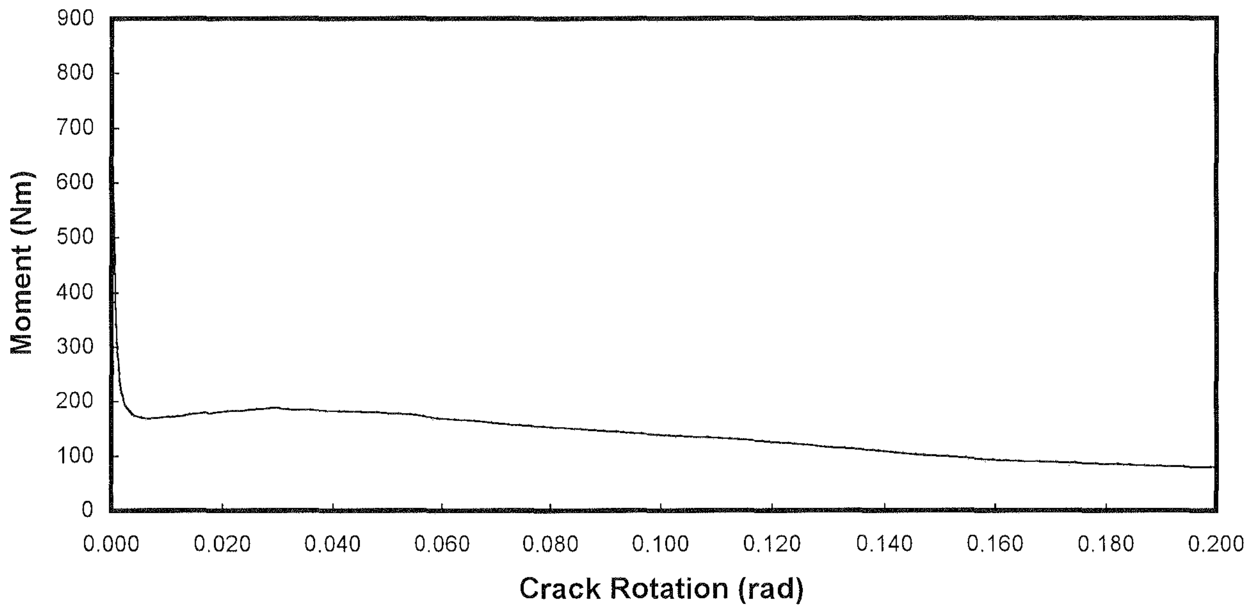
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 5-Jan-01

Specimen: Vinh Crack Rotation Beam V2-C09 **Age:** 107 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span		Measurement and Calculation of Results
Value 1	79.6	123.7	6	45	450	mm	Depth and width are measured adjacent to the crack after
Value 2	80.1	123.7	6	45	Section		completion of test. Very few tests produce more than one
Value 3	79.2	125.9			Modulus		crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	79.6	124.4	6.0	45.0	131515	mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

5.86 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 9.46 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

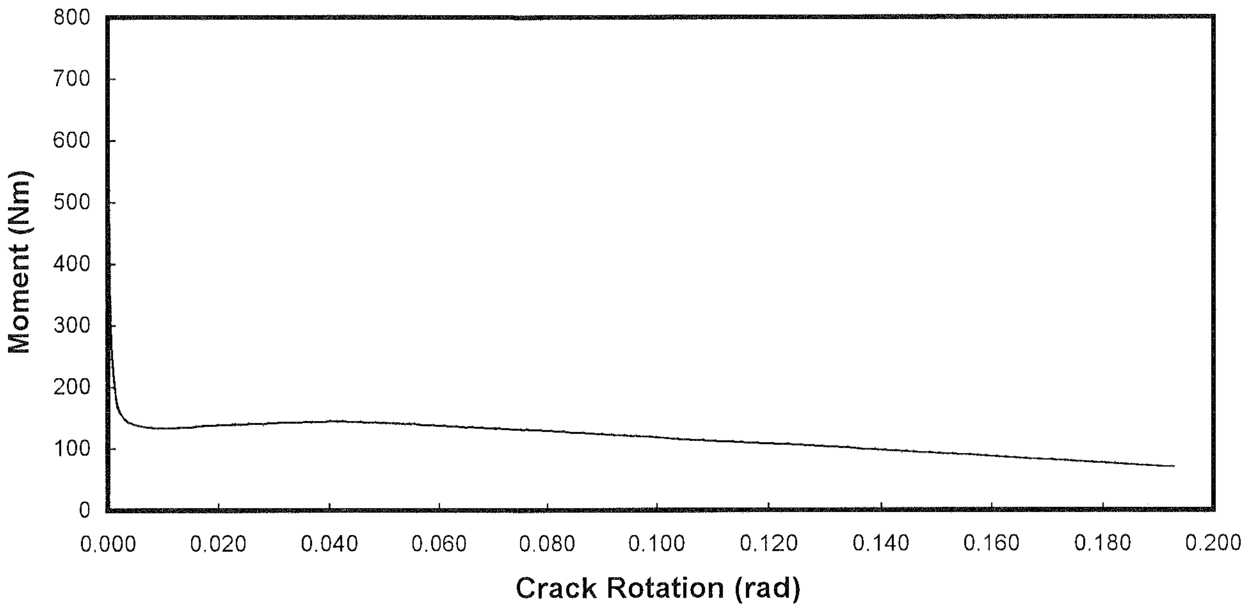
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests — **Date:** 5-Jan-01

Specimen: Vinh Crack Rotation Beam V2-C10 — **Age:** 107 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	75.0	124.0	13	50	450 mm	Depth and width are measured adjacent to the crack after
Value 2	74.4	124.4	12	37	**Section**	completion of test. Very few tests produce more than one
Value 3	74.1	125.0			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	74.5	124.5	12.5	43.5	115137 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

5.87 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 7.27 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

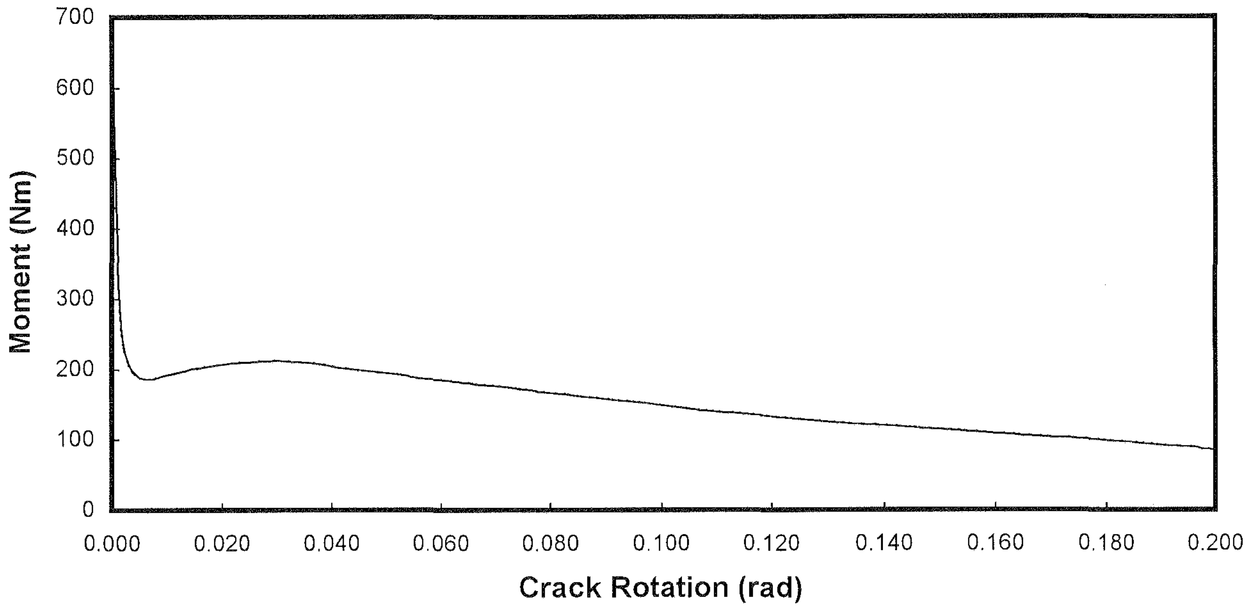
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 5-Jan-01

Specimen: Vinh Crack Rotation Beam V2-C11 **Age:** 107 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	75.0	124.0	13	50	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	74.4	124.4	12	37	**Section Modulus**	
Value 3	74.1	125.0				
Mean	74.5	124.5	12.5	43.5	115137 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

5.66 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 10.52 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

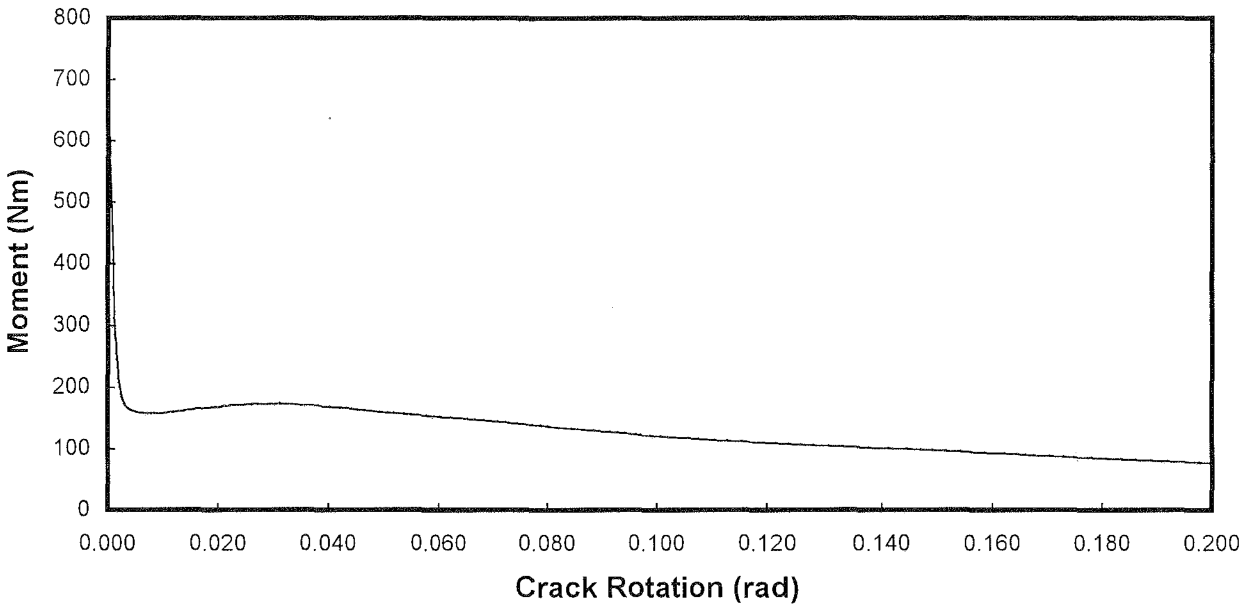
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests — **Date:** 5-Jan-01

Specimen: Vinh Crack Rotation Beam V2-C12 — **Age:** 107 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span		Measurement and Calculation of Results
Value 1	78.0	124.2	-27	41	450	mm	Depth and width are measured adjacent to the crack after
Value 2	78.4	124.2	-15	40	**Section**		completion of test. Very few tests produce more than one
Value 3	77.7	125.7			**Modulus**		crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	78.0	124.7	-21.0	40.5	126554	mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

6.49 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 10.52 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

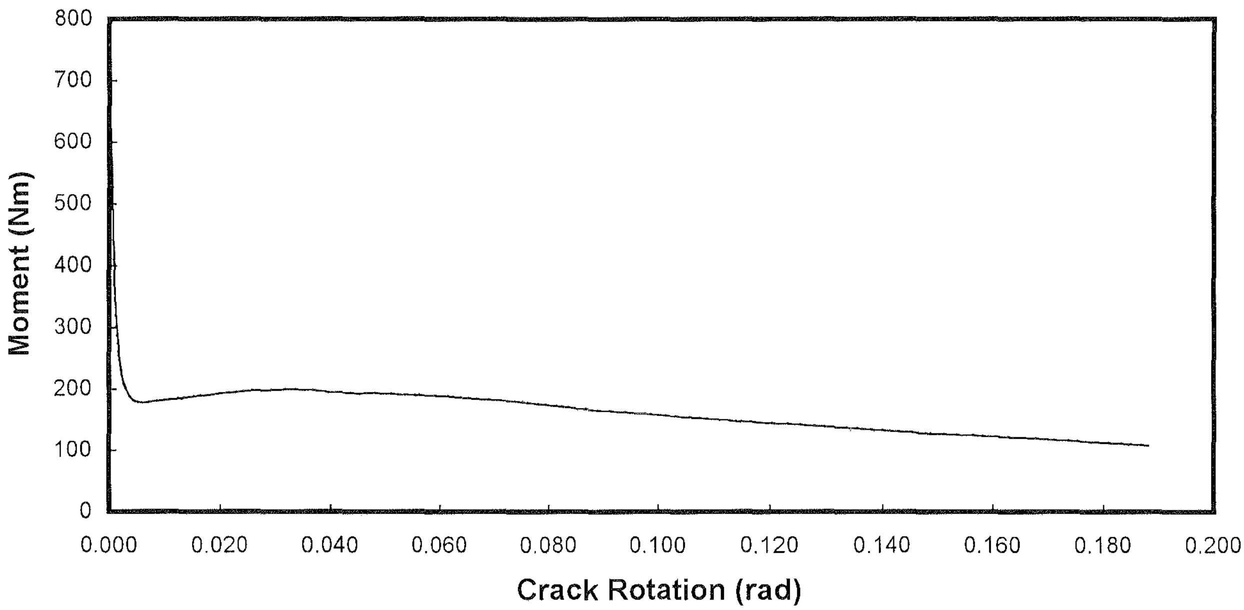
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests — **Date:** 8-Jan-01

Specimen: Vinh Crack Rotation Beam V2-C13 — **Age:** 110 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	76.5	124.2	-11	56	450 mm	Depth and width are measured adjacent to the crack after
Value 2	76.5	124.3	-4	46	**Section**	completion of test. Very few tests produce more than one
Value 3	76.1	124.6			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	76.4	124.4	-7.5	51.0	120882 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

6.51 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 10.16 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

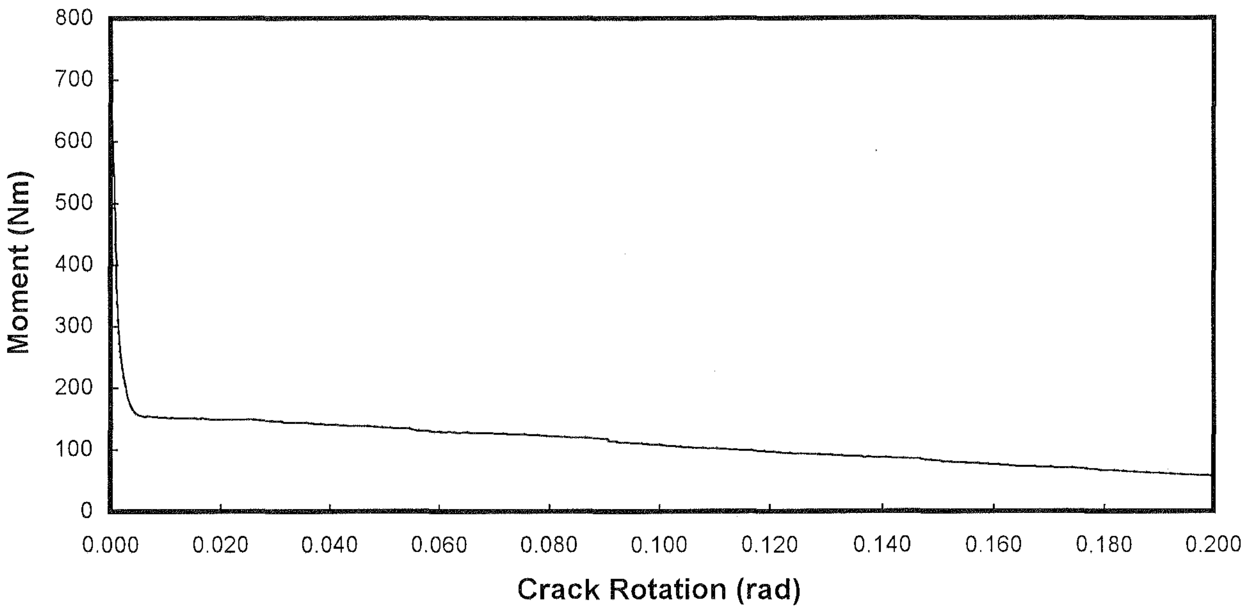
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests — **Date:** 8-Jan-01

Specimen: Vinh Crack Rotation Beam V2-C14 — **Age:** 110 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	77.4	124.1	0	44	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	77.7	122.7	5	39	**Section Modulus**	
Value 3	77.7	124.8				
Mean	77.6	123.9	2.5	41.5	124316 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

5.77 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 8.05 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

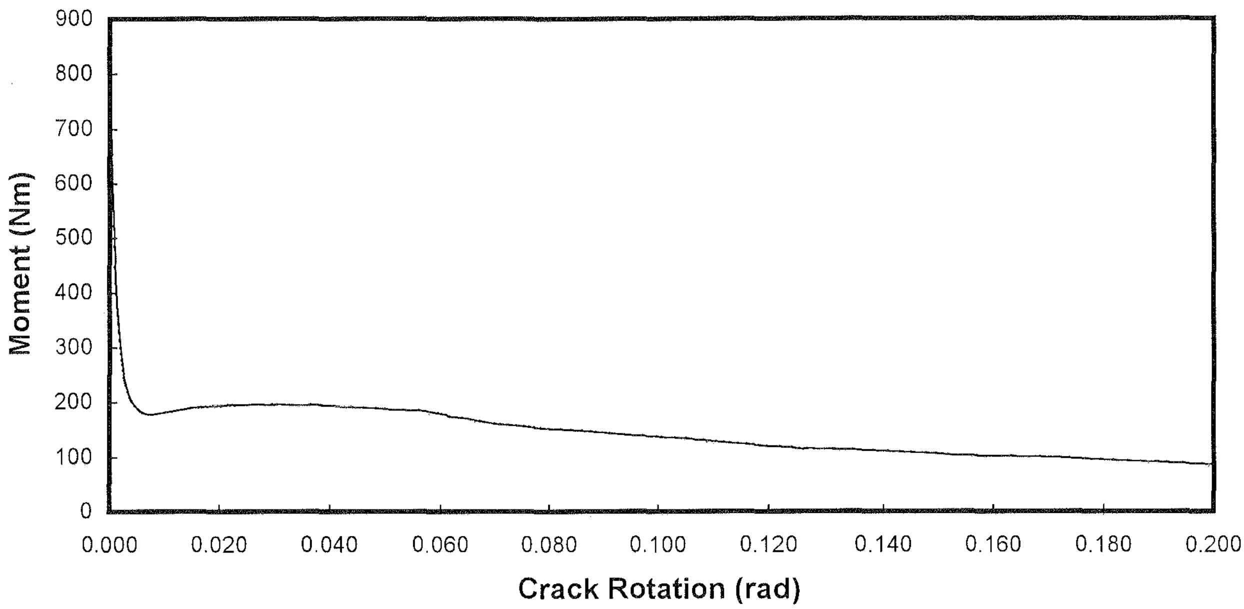
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 8-Jan-01

Specimen: Vinh Crack Rotation Beam V2-C15 **Age:** 110 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span		Measurement and Calculation of Results
Value 1	79.5	126.4	-17	35	450	mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	80.6	125.8	-2	48	**Section Modulus**		
Value 3	81.0	127.6					
Mean	80.4	126.6	-9.5	41.5	136281	mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

6.23 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 10.30 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

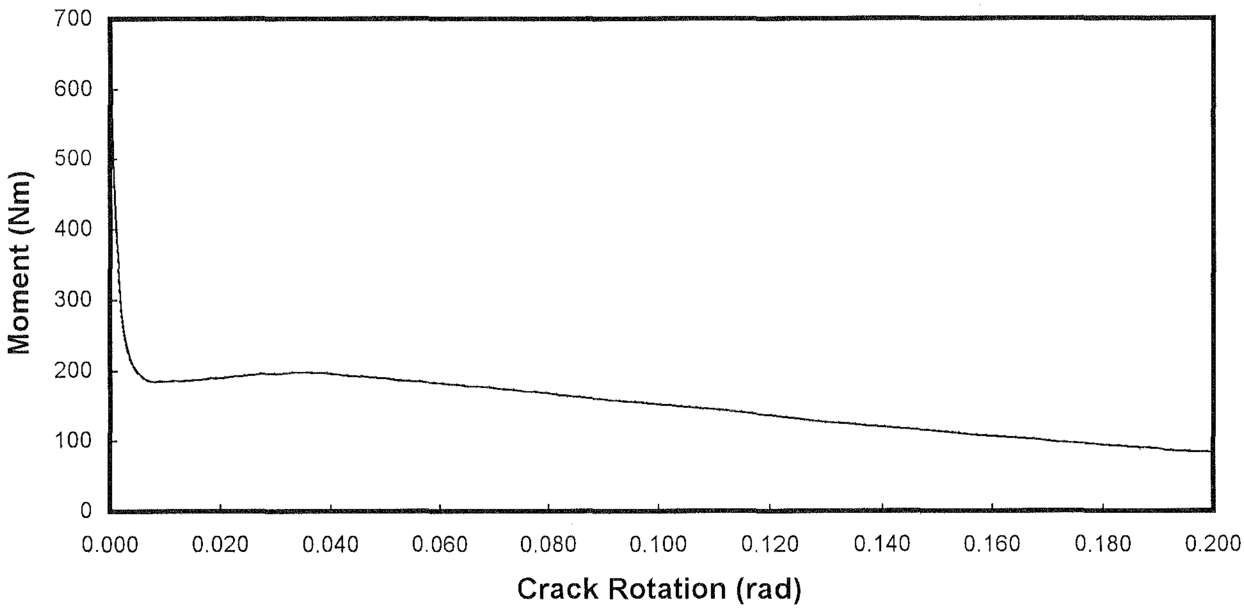
The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests | **Date:** 8-Jan-01
Specimen: Vinh Crack Rotation Beam V2-C16 | **Age:** 110 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	74.4	125.6	-12	35	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	73.0	125.4	0	48	**Section Modulus**	
Value 3	75.1	126.5				
Mean	74.2	125.8	-6.0	41.5	115362 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

6.02 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 10.25 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

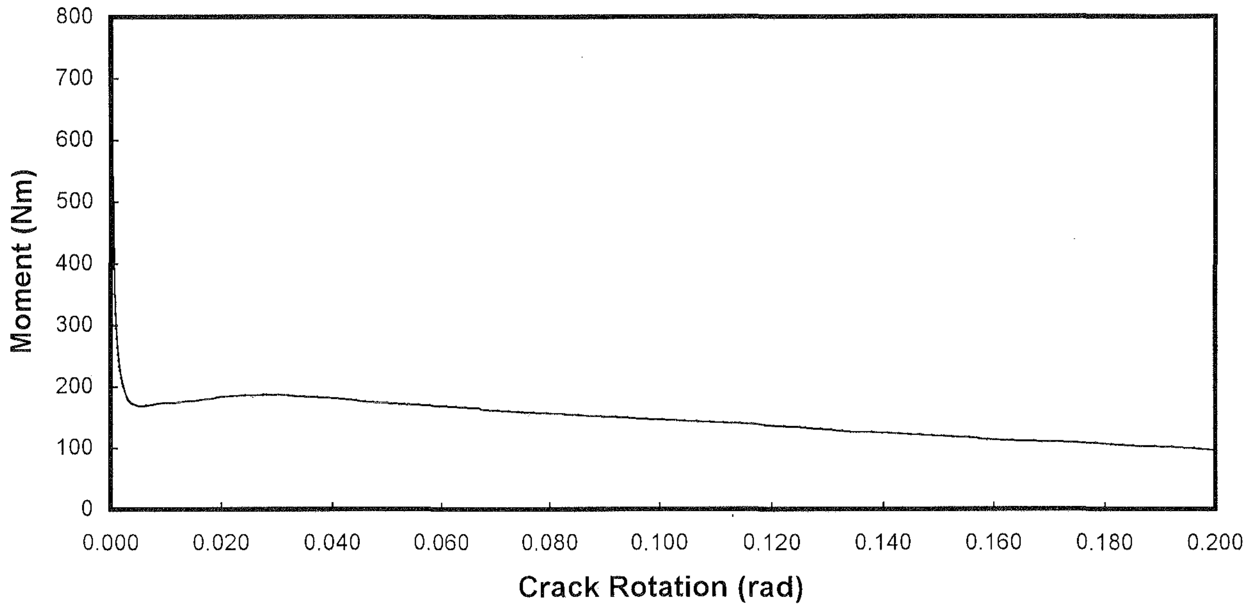
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 8-Jan-01

Specimen: Vinh Crack Rotation Beam V2-C17 **Age:** 110 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span		Measurement and Calculation of Results
Value 1	78.2	124.3	-7	46	450	mm	Depth and width are measured adjacent to the crack after
Value 2	78.9	124.4	-6	43	Section		completion of test. Very few tests produce more than one
Value 3	79.2	125.2			Modulus		crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	78.8	124.6	-6.5	44.5	128875	mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

5.60 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 9.38 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

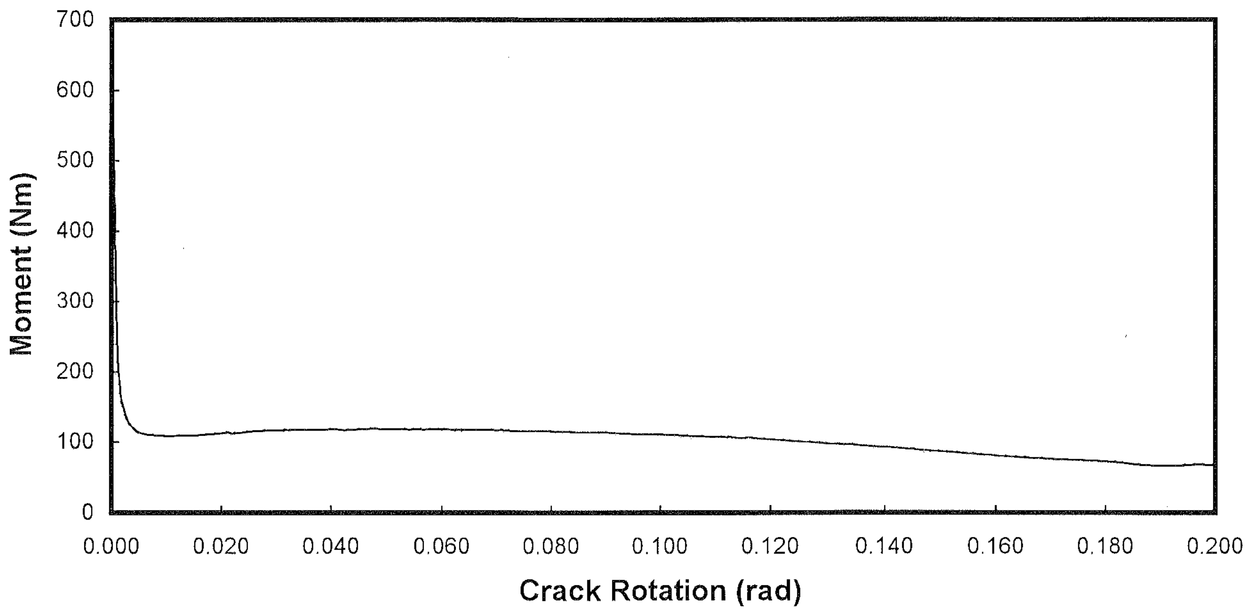
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: **Comparative Beam and Panel Tests** Date: **8-Jan-01**

Specimen: **Vinh Crack Rotation Beam V2-C18** Age: **110 days**



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	
Value 1	77.3	124.6	-36	44	450	mm
Value 2	77.5	123.7	-24	44	**Section Modulus**	
Value 3	75.8	124.9				
Mean	76.9	124.4	-30.0	44.0	122503	mm^3

Measurement and Calculation of Results

Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

6.35 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 5.94 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Forta Synergy fibres were used in this batch.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

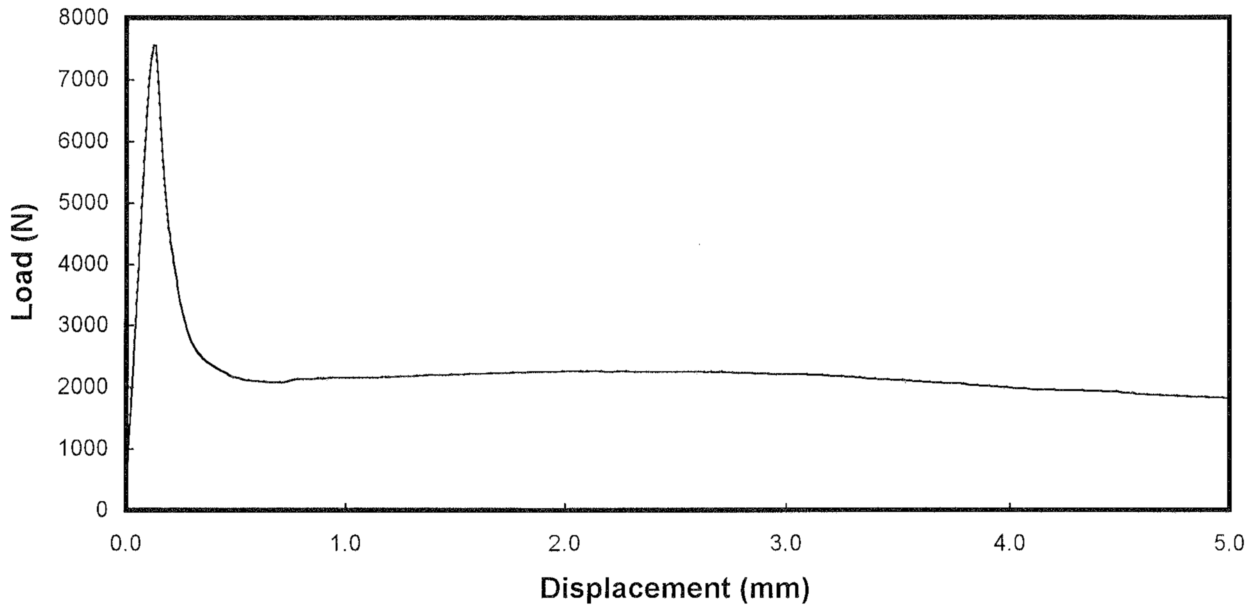
The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Compartive Beam and Panel Tests **Date:** 8-Jan-01
Specimen: 75x125mm Beam v2-c19 **Age:** 110 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	76.0	127.3	46	44	450 mm	Depth and width are measured adjacent to the crack after
Value 2	73.7	127.7	23	49	**Section**	completion of test. Very few tests produce more than one
Value 3	73.8	125.4			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	74.5	126.8	34.5	46.5	117295 mm^3	used to find flexural and residual strengths.

Crack offset represents the distance of each end of the crack from the centre of the beam. All fibres are counted on each crack face.

Flexural Strengths

4.84	MPa	Modulus of Rupture		
1.38	MPa	Residual Flexural Strength	0.50	mm central deflection.
1.42	MPa	Residual Flexural Strength	3.00	mm central deflection.

Toughness Parameters

ASTM Toughness Indices

I_5	2.70	I_{10}	3.91	I_{20}	6.33
I_{30}	8.84	I_{50}	13.87		

Japanese Toughness Indices

T_{JCSE}	7.37	Nm, up to 3.0 mm displacement
F_{JCSE}	1.57	MPa, up to 3.0 mm displacement

Comments

Condition of Failed Specimen

Concrete matrix had a moderate air content.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper rollers could swivel in tandem.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with dual side-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

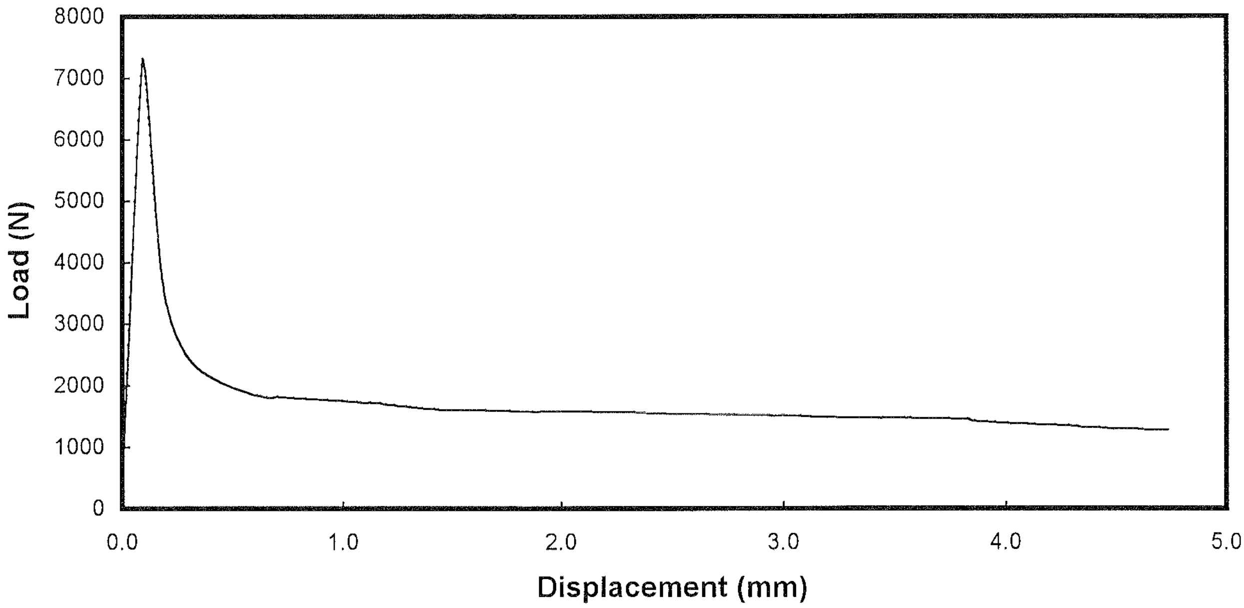
University of Western Sydney

Engineering and Industrial Design

Fibre Reinforced Concrete Beam Test Result

Client: Compartive Beam and Panel Tests **Date:** 8-Jan-01

Specimen: 75x125mm Beam v2-c20 **Age:** 110 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	77.8	128.3	14	47	450 mm	Depth and width are measured adjacent to the crack after
Value 2	79.0	126.4	41	37	**Section**	completion of test. Very few tests produce more than one
Value 3	77.2	126.5			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	78.0	127.1	27.5	42.0	128846 mm^3	used to find flexural and residual strengths.

Crack offset represents the distance of each end of the crack from the centre of the beam. All fibres are counted on each crack face.

Flexural Strengths

4.27	MPa	Modulus of Rupture		
1.15	MPa	Residual Flexural Strength	0.50	mm central deflection.
0.88	MPa	Residual Flexural Strength	3.00	mm central deflection.

Toughness Parameters

ASTM Toughness Indices

I_5	3.04	I_{10}	4.36	I_{20}	6.57
I_{30}	8.63	I_{50}	12.48		

Japanese Toughness Indices

T_{JCSE}	5.75	Nm, up to 3.0 mm displacement
F_{JCSE}	1.12	MPa, up to 3.0 mm displacement

Comments

Condition of Failed Specimen

Concrete matrix had a moderate air content.
Fibres were well distributed.

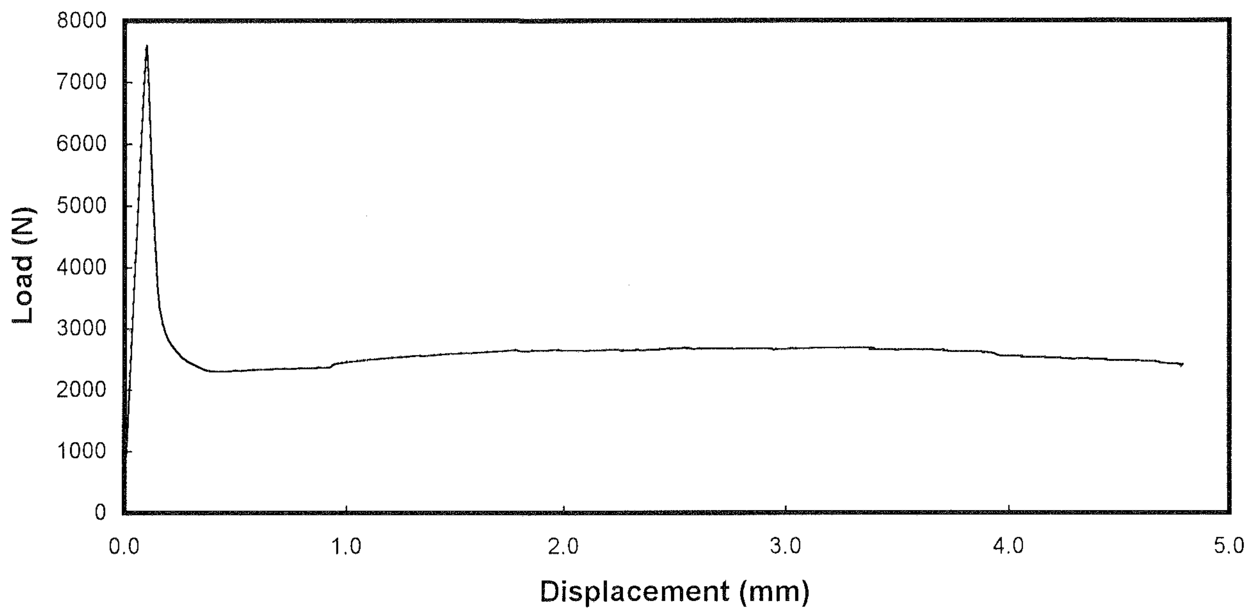
Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper rollers could swivel in tandem.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with dual side-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney
Engineering and Industrial Design
Fibre Reinforced Concrete Beam Test Result

Client: Compartive Beam and Panel Tests **Date:** 8-Jan-01
Specimen: 75x125mm Beam v2-c21 **Age:** 110 days



Dimensional Data
(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	73.6	125.9	41	46	450 mm	Depth and width are measured adjacent to the crack after
Value 2	73.9	126.2	67	51	**Section**	completion of test. Very few tests produce more than one
Value 3	75.6	126.9			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	74.4	126.3	54.0	48.5	116446 mm^3	used to find flexural and residual strengths.

Crack offset represents the distance of each end of the crack from the centre of the beam. All fibres are counted on each crack face.

Flexural Strengths

4.91	MPa	Modulus of Rupture		
1.46	MPa	Residual Flexural Strength	0.50	mm central deflection.
1.72	MPa	Residual Flexural Strength	3.00	mm central deflection.

Toughness Parameters

ASTM Toughness Indices

I_5	2.69	I_{10}	4.09	I_{20}	6.96
I_{30}	10.05	I_{50}	16.47		

Japanese Toughness Indices

T_{JCSE}	8.00	Nm, up to 3.0 mm displacement
F_{JCSE}	1.72	MPa, up to 3.0 mm displacement

Comments

Condition of Failed Specimen

Concrete matrix had a moderate air content.
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper rollers could swivel in tandem.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with dual side-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

2.1.3. Concrete Set 3

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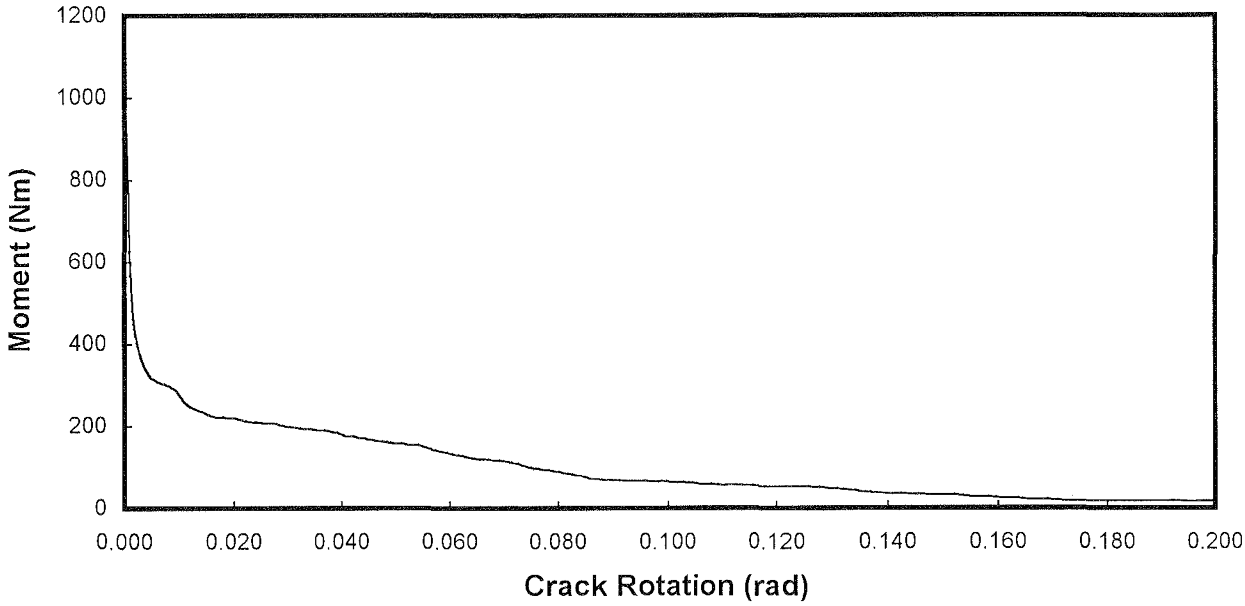
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 17-Jan-01

Specimen: Vinh Crack Rotation Beam V3-C01 **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	78.1	126.3	0	10	450 mm	Depth and width are measured adjacent to the crack after
Value 2	77.9	127.0	-24	20	**Section**	completion of test. Very few tests produce more than one
Value 3	78.2	124.9			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	78.1	126.1	-12.0	15.0	128050 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

8.45 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 11.96 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

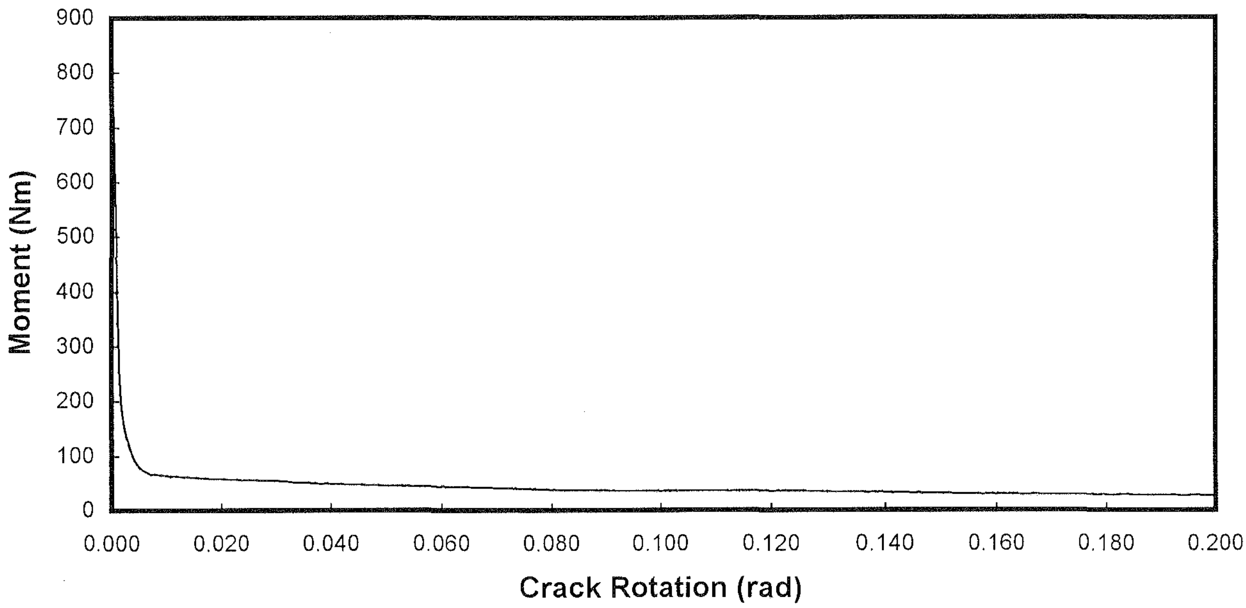
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: **Comparative Beam and Panel Tests** Date: **17-Jan-01**

Specimen: **Vinh Crack Rotation Beam V3-C02** Age: **91 days**



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	73.8	123.6	21	11	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	74.7	123.5	0	13	**Section Modulus**	
Value 3	73.4	119.1				
Mean	74.0	122.1	10.5	12.0	111306 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.48 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 3.79 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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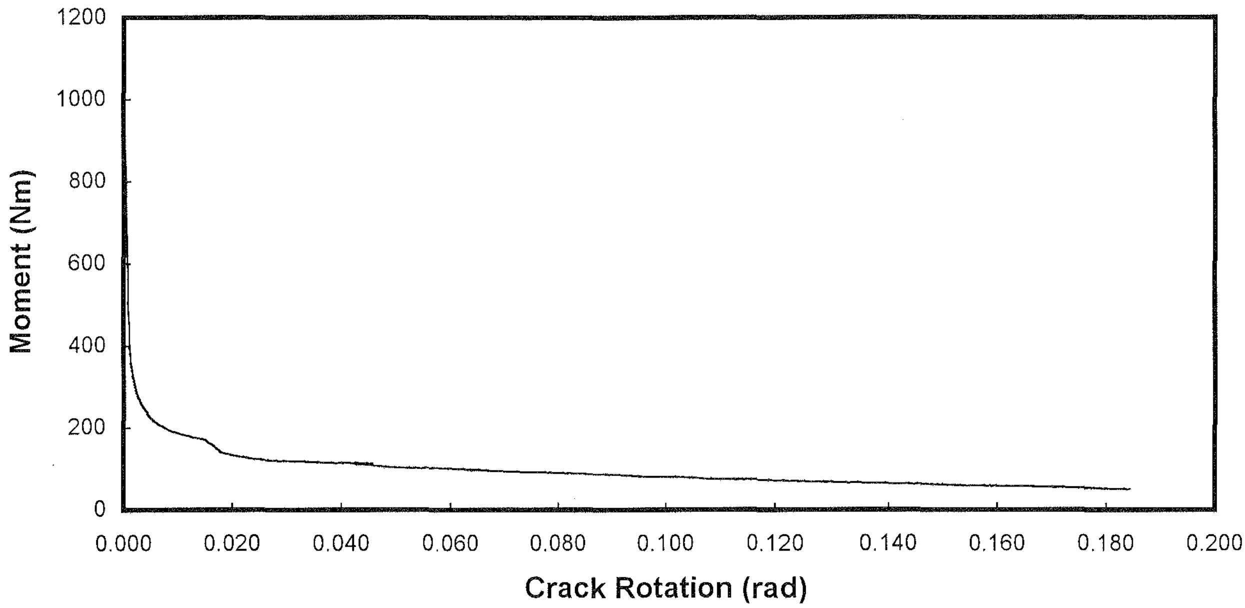
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 17-Jan-01
Specimen: Vinh Crack Rotation Beam V3-C03 **Age:** 91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	78.1	123.4	12	13	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	78.8	123.2	0	17	**Section Modulus**	
Value 3	78.3	123.1				
Mean	78.4	123.2	6.0	15.0	126244 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

8.44 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 8.08 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

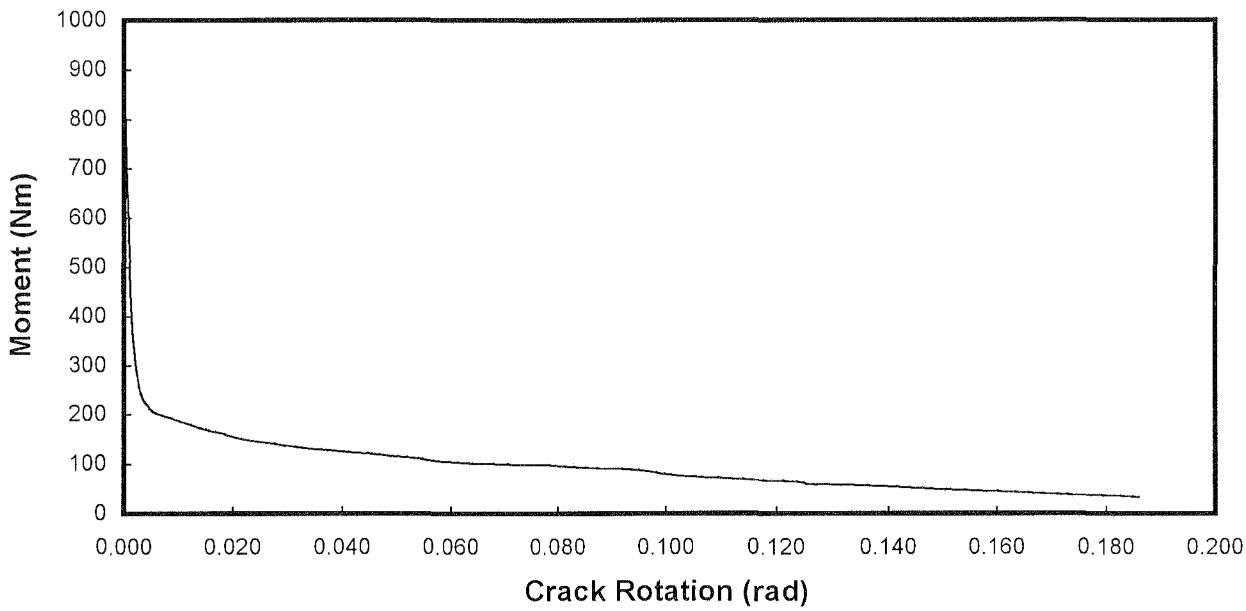
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 17-Jan-01

Specimen: Vinh Crack Rotation Beam V3-C04 **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	75.9	120.5	-35	11	450 mm	Depth and width are measured adjacent to the crack after
Value 2	77.2	120.6	-19	19	**Section**	completion of test. Very few tests produce more than one
Value 3	76.0	123.4			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	76.4	121.5	-27.0	15.0	118095 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

9.56 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 8.48 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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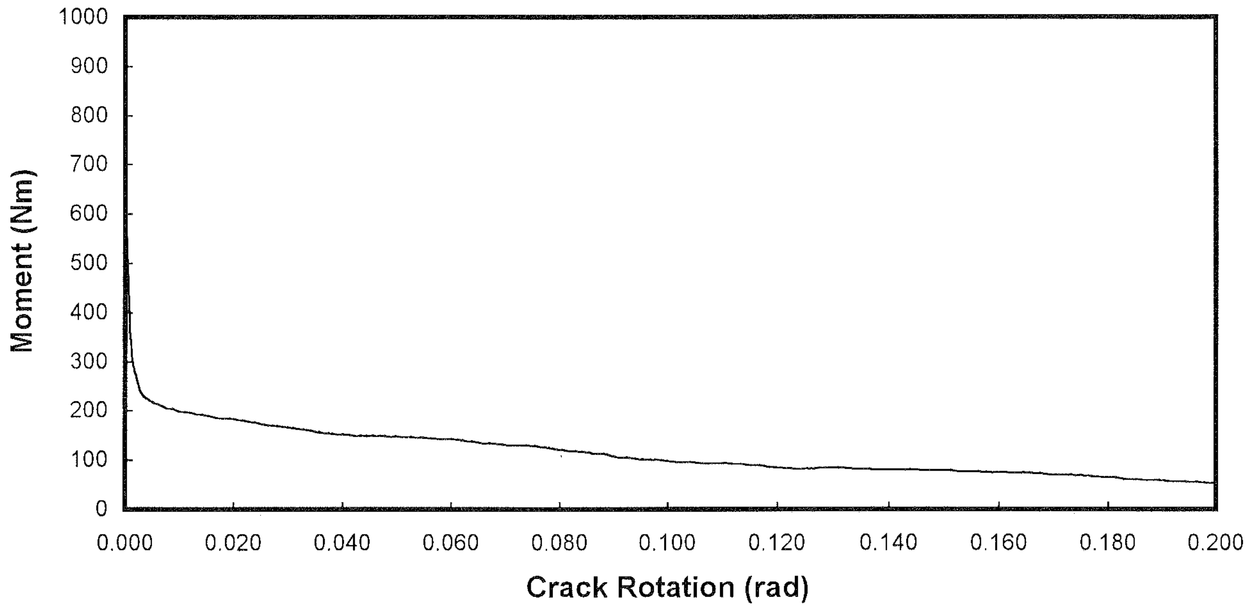
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 17-Jan-01

Specimen: Vinh Crack Rotation Beam V3-C05 **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	76.4	123.1	22	14	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	77.6	122.8	10	13	**Section Modulus**	
Value 3	75.9	123.5				
Mean	76.6	123.1	16.0	13.5	120520 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.67 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 9.18 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

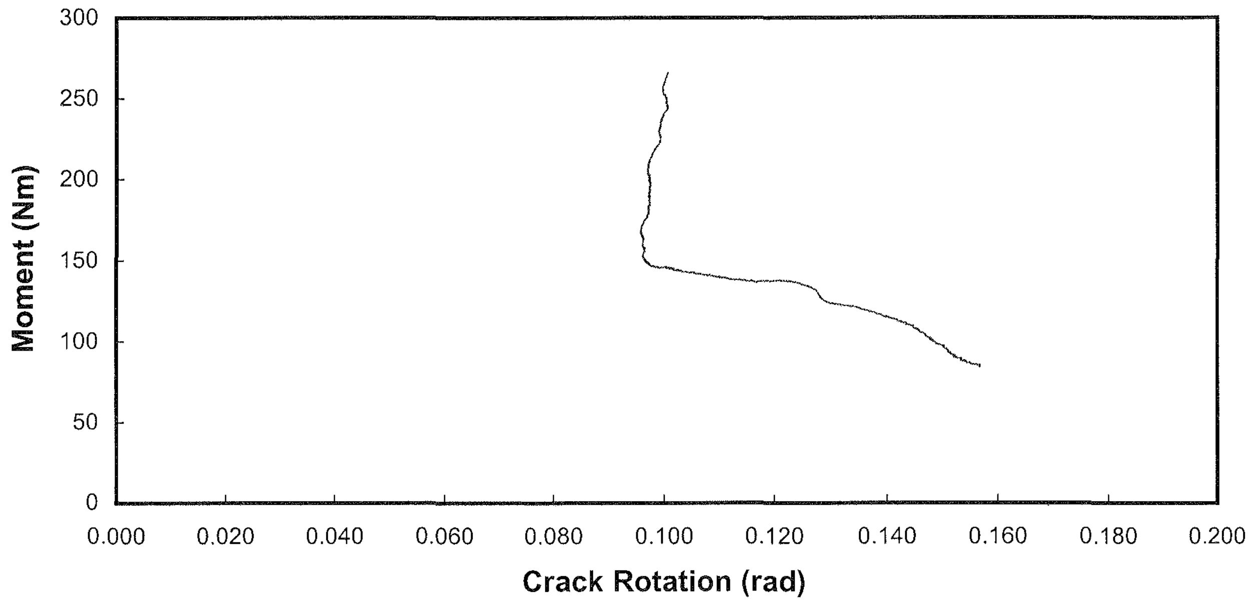
Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney, Nepean
Civic Engineering and Environment
Fibre Reinforced Concrete Beam Test Result

Client: **Comparative Beam and Panel Tests** Date: 17-Jan-01
Specimen: Vinh Crack Rotation Beam V3-C06 Age: 91 days



Dimensional Data
(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	75.3	126.6	0	12	450 mm	Depth and width are measured adjacent to the crack after
Value 2	74.9	125.4	-12	18	**Section**	completion of test. Very few tests produce more than one
Value 3	75.7	127.2			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	75.3	126.4	-6.0	15.0	119450 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.93 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotatic 9.18 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

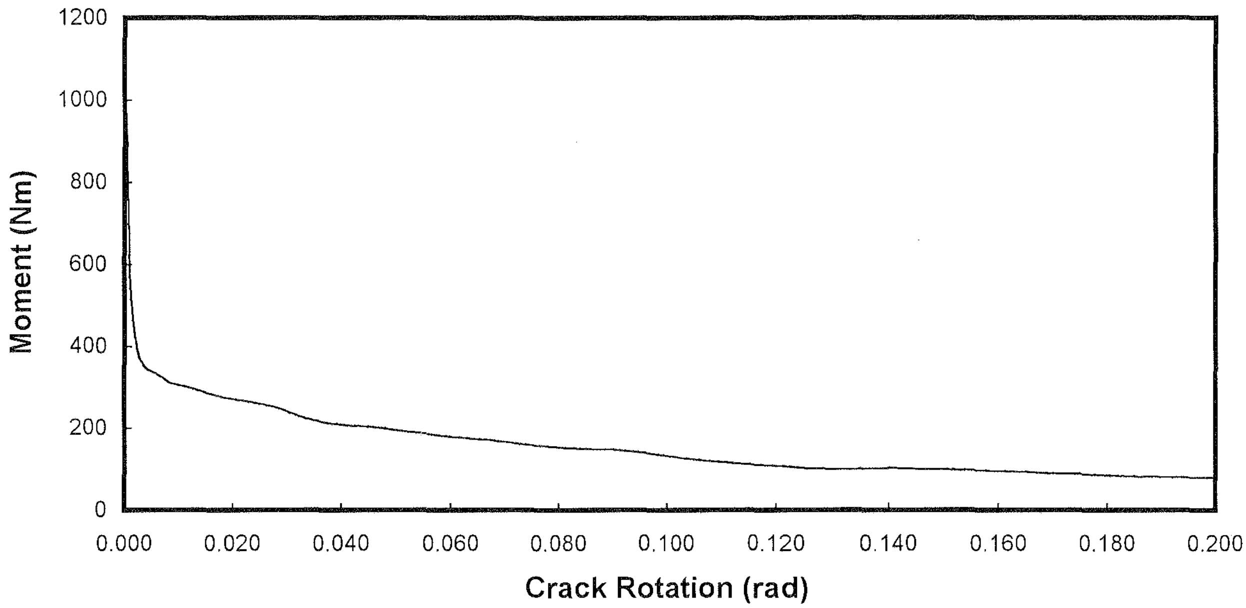
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 17-Jan-01

Specimen: Vinh Crack Rotation Beam V3-C07 **Age:** 91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	77.0	123.1	0	16	450 mm	Depth and width are measured adjacent to the crack after
Value 2	76.9	123.1	-7	24	**Section**	completion of test. Very few tests produce more than one
Value 3	76.9	124.3			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	76.9	123.5	-3.5	20.0	121827 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

8.85 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 13.97 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney, Nepean

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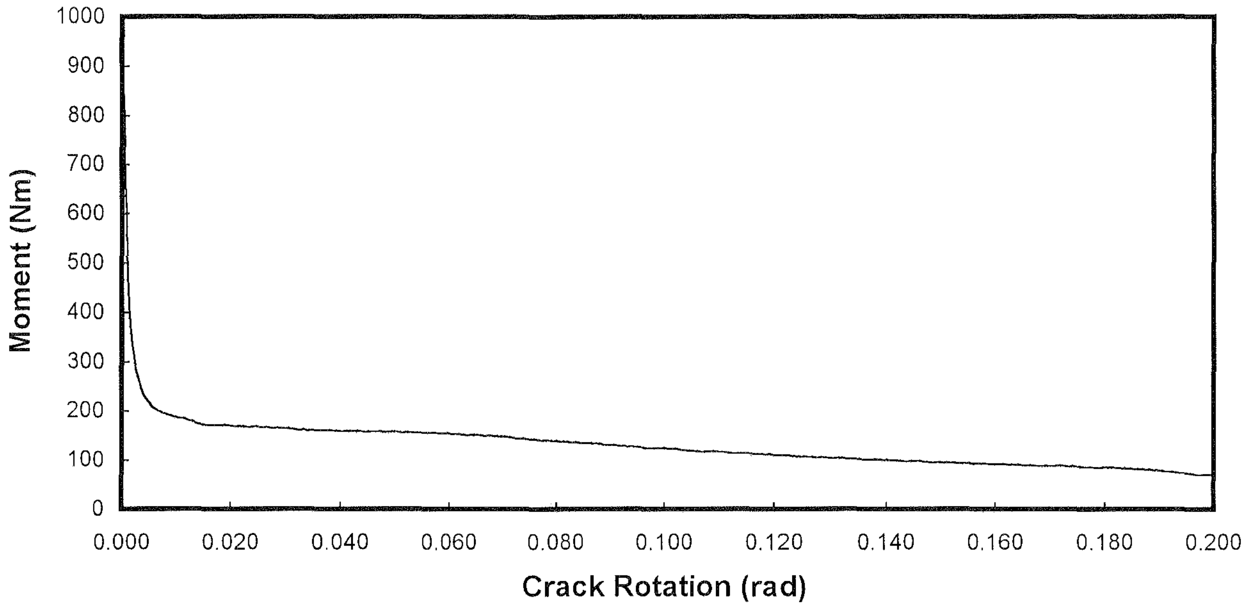
Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 17-Jan-01

Specimen: Vinh Crack Rotation Beam V3-C08 **Age:** 91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	76.6	124.7	13	17	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	77.0	125.4	9	15	**Section Modulus**	
Value 3	77.2	125.5				
Mean	76.9	125.2	11.0	16.0	123504 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.61 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 9.58 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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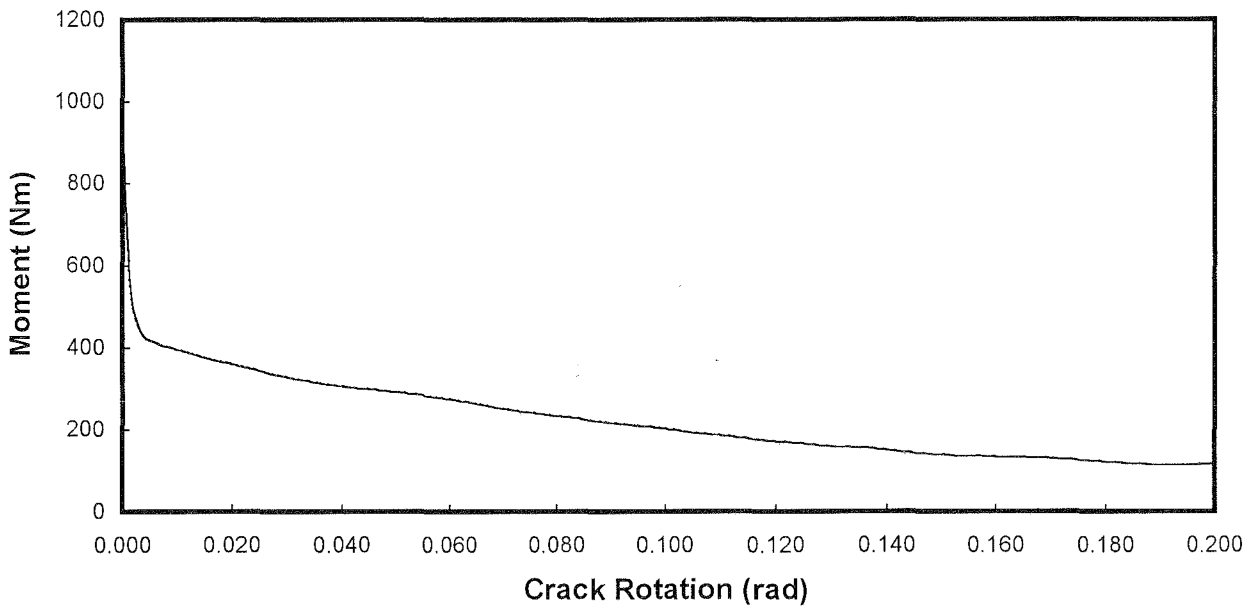
Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 17-Jan-01

Specimen: Vinh Crack Rotation Beam V3-C09 **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	77.6	125.0	3	14	450 mm	Depth and width are measured adjacent to the crack after
Value 2	76.7	124.1	0	15	**Section**	completion of test. Very few tests produce more than one
Value 3	77.6	126.1			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	77.3	125.1	1.5	14.5	124552 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

8.00 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 18.12 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney, Nepean

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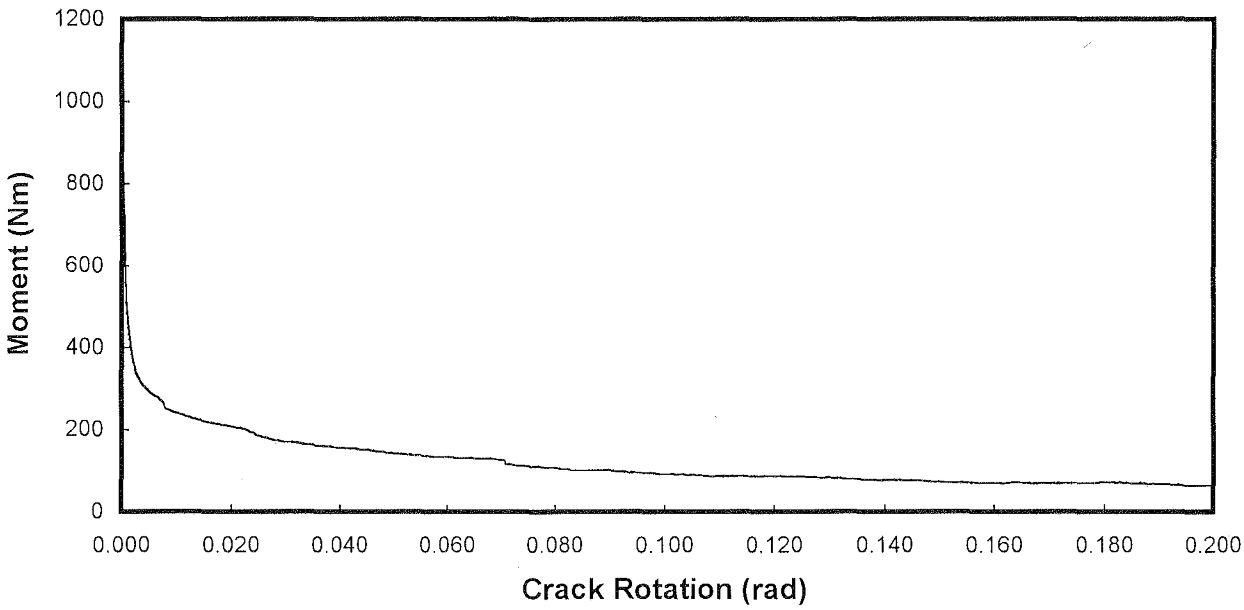
Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 17-Jan-01

Specimen: Vinh Crack Rotation Beam V3-C10 **Age:** 91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	77.0	123.4	9	20	450 mm	Depth and width are measured adjacent to the crack after
Value 2	77.8	123.5	25	16	**Section**	completion of test. Very few tests produce more than one
Value 3	77.4	124.2			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	77.4	123.7	17.0	18.0	123510 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.70 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 10.59 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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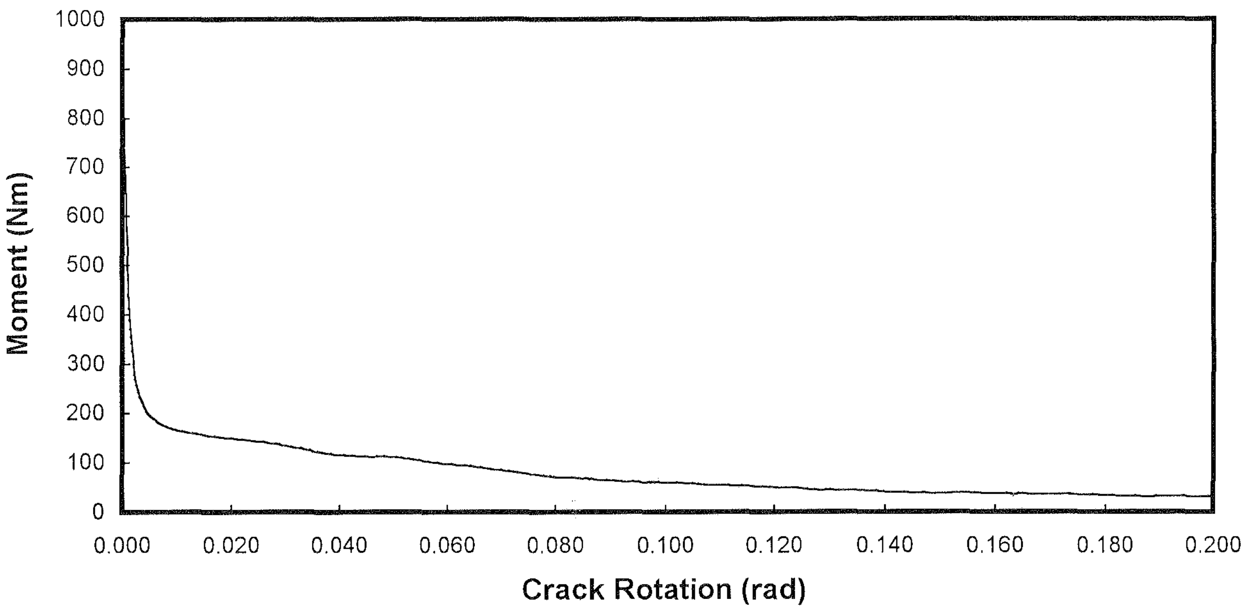
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: **Comparative Beam and Panel Tests** **Date:** **17-Jan-01**

Specimen: **Vinh Crack Rotation Beam V3-C11** **Age:** **91 days**



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	77.5	123.2	0	11	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	76.5	124.2	-9	12	**Section Modulus**	
Value 3	77.3	124.3				
Mean	77.1	123.9	-4.5	11.5	122752 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.55 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 8.03 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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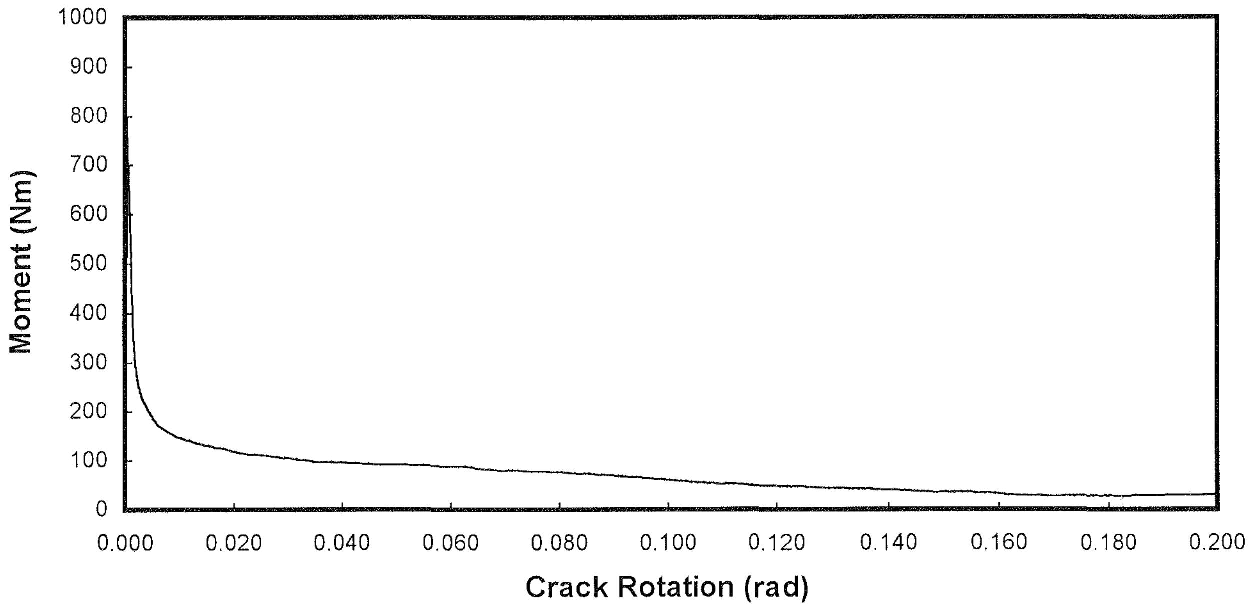
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 17-Jan-01

Specimen: Vinh Crack Rotation Beam V3-C12 **Age:** 91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span		Measurement and Calculation of Results
Value 1	79.5	125.9	-30	23	450	mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	78.8	124.9	-20	20	**Section Modulus**		
Value 3	77.2	126.3					
Mean	78.5	125.7	-25.0	21.5	129099	mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 43 mm Lever arm to Strain 2 41 mm

Flexural Strength

9.22 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 7.04 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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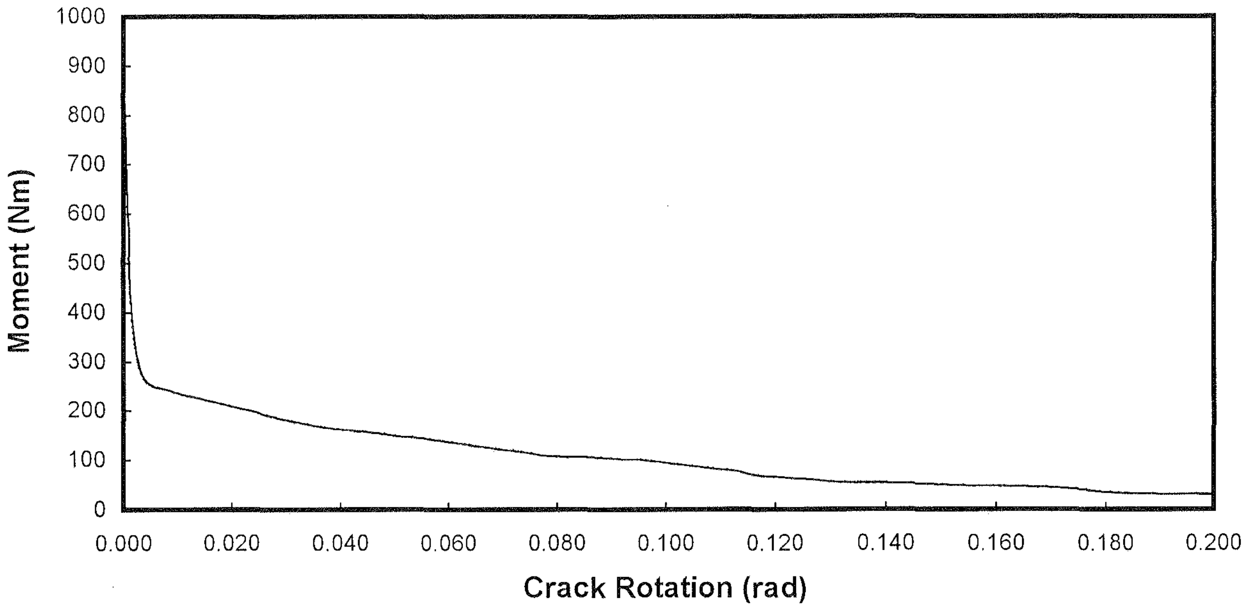
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: **Comparative Beam and Panel Tests** Date: **17-Jan-01**

Specimen: **Vinh Crack Rotation Beam V3-C13** Age: **91 days**



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span
Value 1	74.7	125.0	12	19	450 mm
Value 2	75.0	124.2	16	18	**Section Modulus**
Value 3	78.0	125.9			
Mean	75.9	125.0	14.0	18.5	120049 mm^3

Measurement and Calculation of Results

Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 44 mm Lever arm to Strain 2 40 mm

Flexural Strength

7.87 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 10.62 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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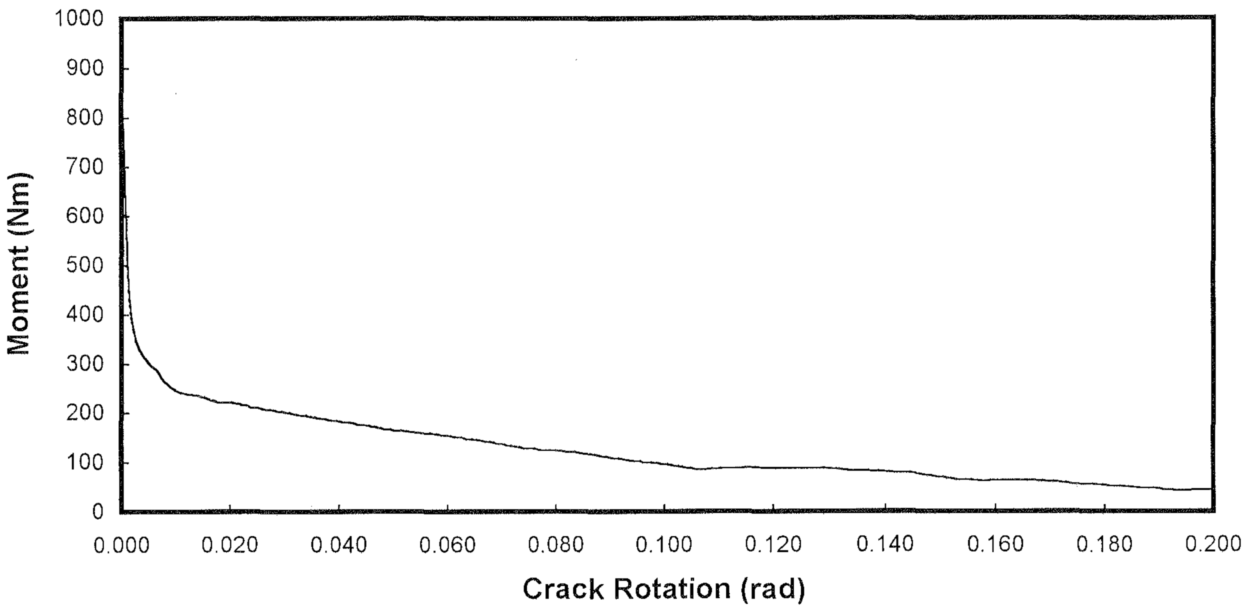
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client:	Comparative Beam and Panel Tests	Date:	17-Jan-01
Specimen:	Vinh Crack Rotation Beam V3-C14	Age:	91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	77.6	123.9	0	19	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	77.0	123.2	-6	19	**Section**	
Value 3	74.4	124.0			**Modulus**	
Mean	76.3	123.7	-3.0	19.0	120129 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.89 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 11.60 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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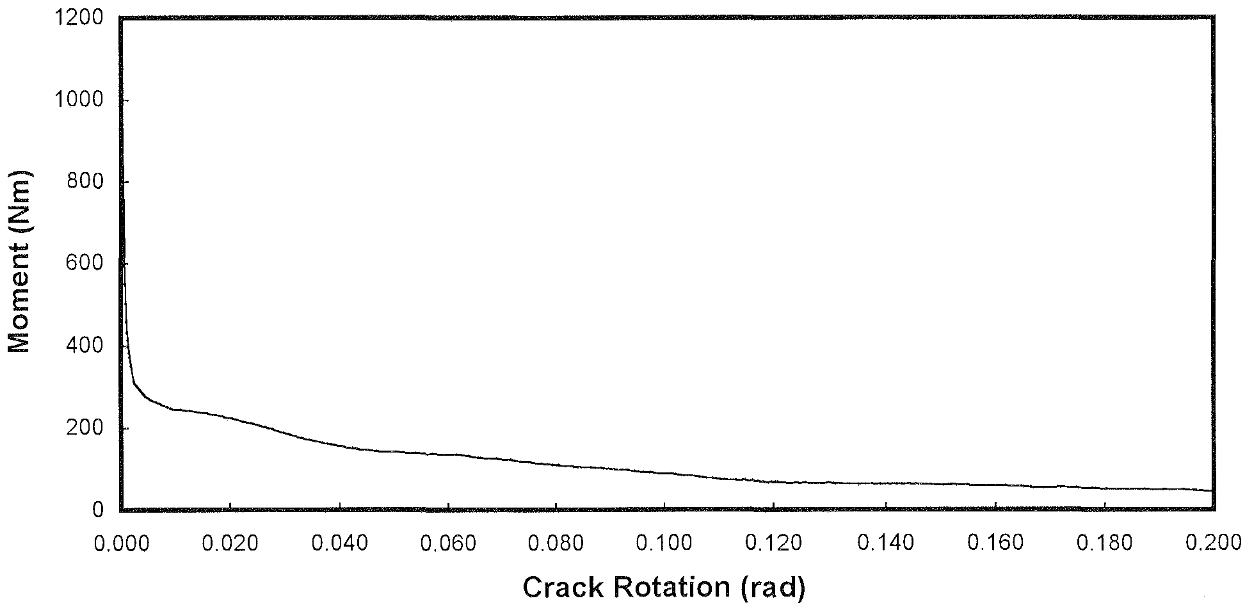
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests — **Date:** 17-Jan-01

Specimen: Vinh Crack Rotation Beam V3-C15 — **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	78.1	121.4	-10	29	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	78.0	121.7	-4	24	**Section Modulus**	
Value 3	78.1	123.2				
Mean	78.1	122.1	-7.0	26.5	124021 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 43 mm Lever arm to Strain 2 41 mm

Flexural Strength

9.05 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 10.87 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

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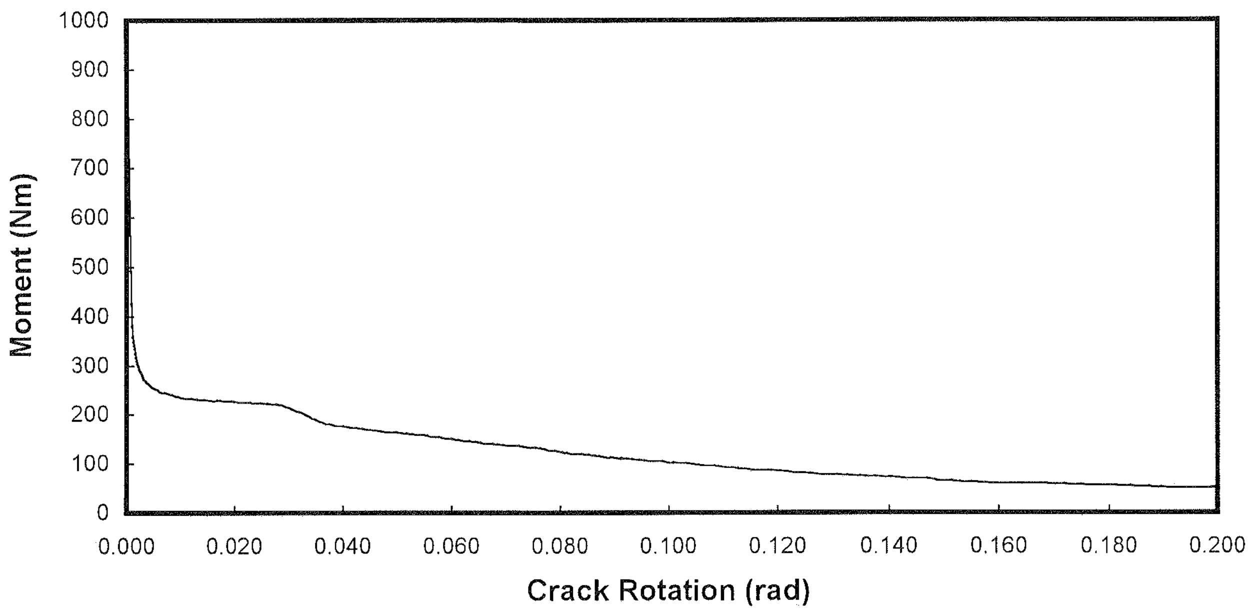
Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 17-Jan-01

Specimen: Vinh Crack Rotation Beam V3-C16 **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	80.6	124.0	0	32	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	77.4	121.8	-19	21	**Section Modulus**	
Value 3	73.9	123.8				
Mean	77.3	123.2	-9.5	26.5	122693 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

8.20 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 11.21 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

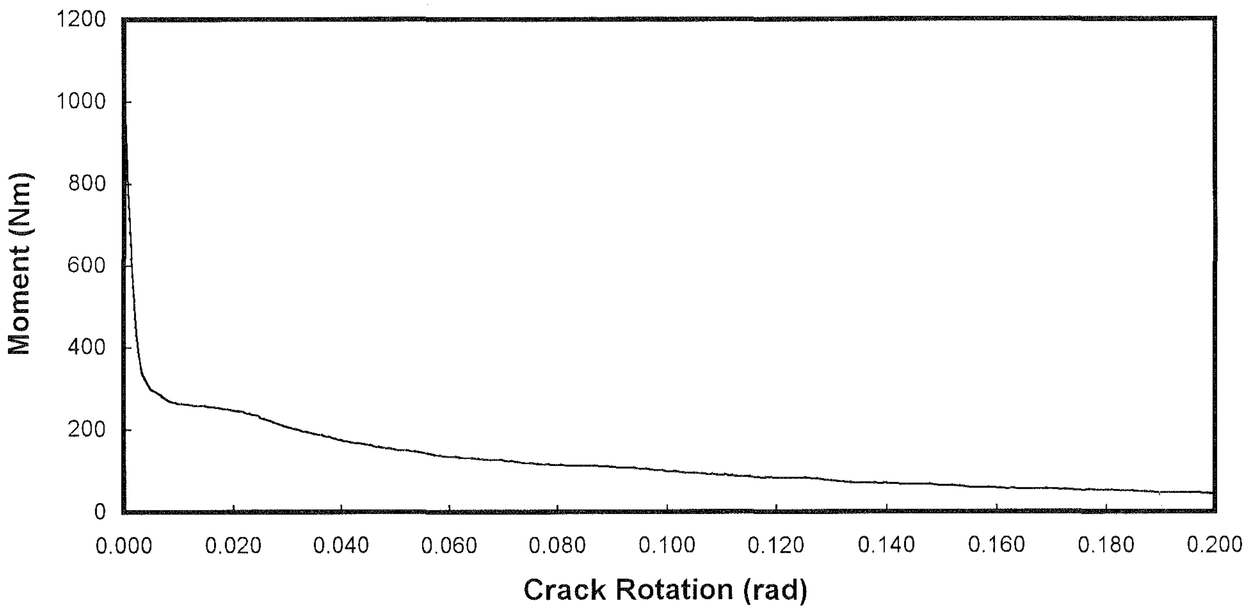
The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client:	Comparative Beam and Panel Tests	Date:	17-Jan-01
Specimen:	Vinh Crack Rotation Beam V3-C16	Age:	91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	79.4	125.4	2	23	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	79.0	127.9	4	21	**Section Modulus**	
Value 3	78.7	125.0				
Mean	79.0	126.1	3.0	22.0	131276 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 44 mm Lever arm to Strain 2 40 mm

Flexural Strength

7.94 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 12.31 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

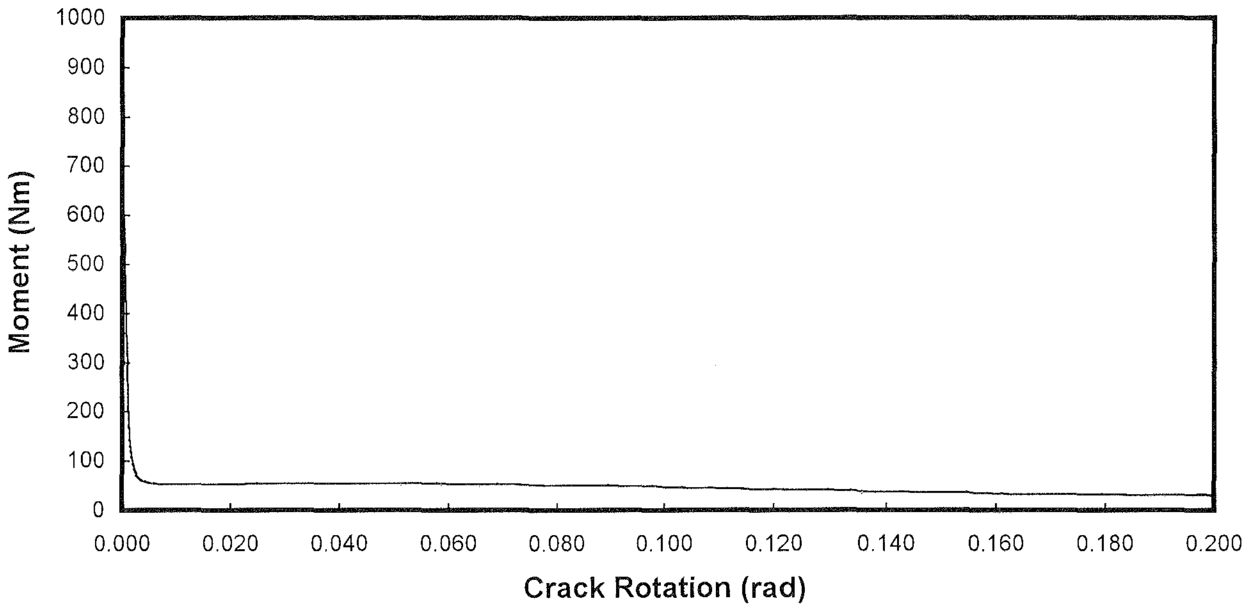
Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

2.1.4. Concrete Set 4

University of Western Sydney, Nepean
Civic Engineering and Environment
Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests — **Date:** 31-Jan-01
Specimen: Vinh Crack Rotation Beam V4-C01 — **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	76.6	123.7	0	-9	450 mm	Depth and width are measured adjacent to the crack after
Value 2	76.6	123.4	0	-14	Section	completion of test. Very few tests produce more than one
Value 3	76.4	124.7			Modulus	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	76.5	123.9	0.0	-11.5	120987 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.50 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 3.50 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

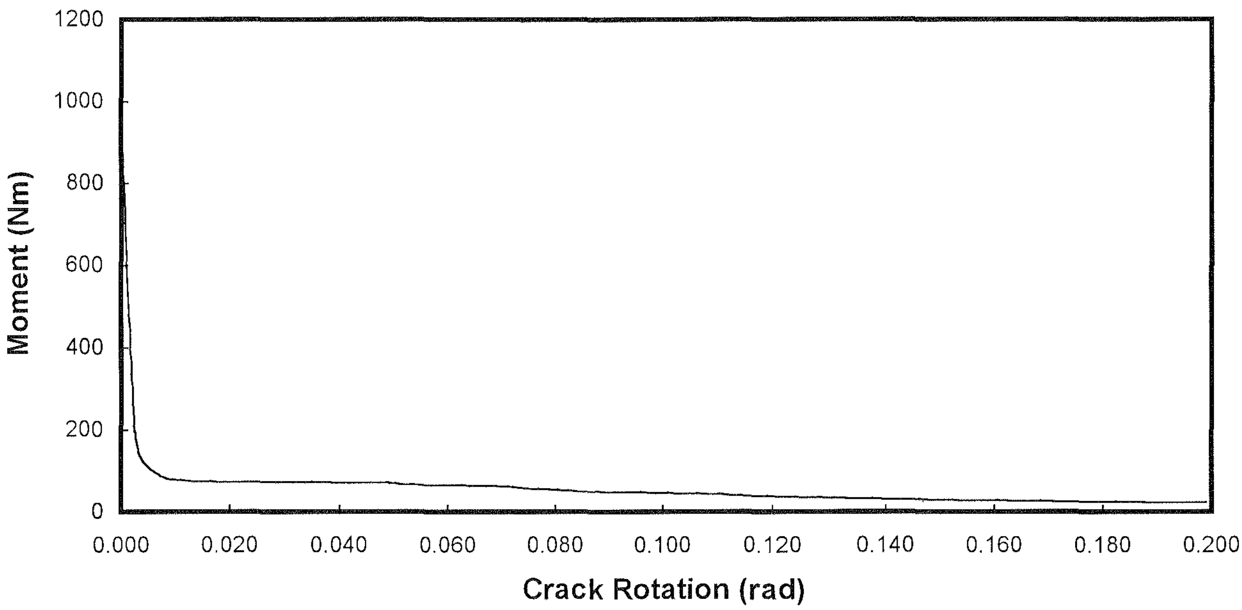
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 31-Jan-01

Specimen: Vinh Crack Rotation Beam V4-C02 **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	79.4	127.5	-4	11	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	78.8	127.6	-6	18	**Section**	
Value 3	81.5	126.2			**Modulus**	
Mean	79.9	127.1	-5.0	14.5	135235 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.57 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 5.06 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

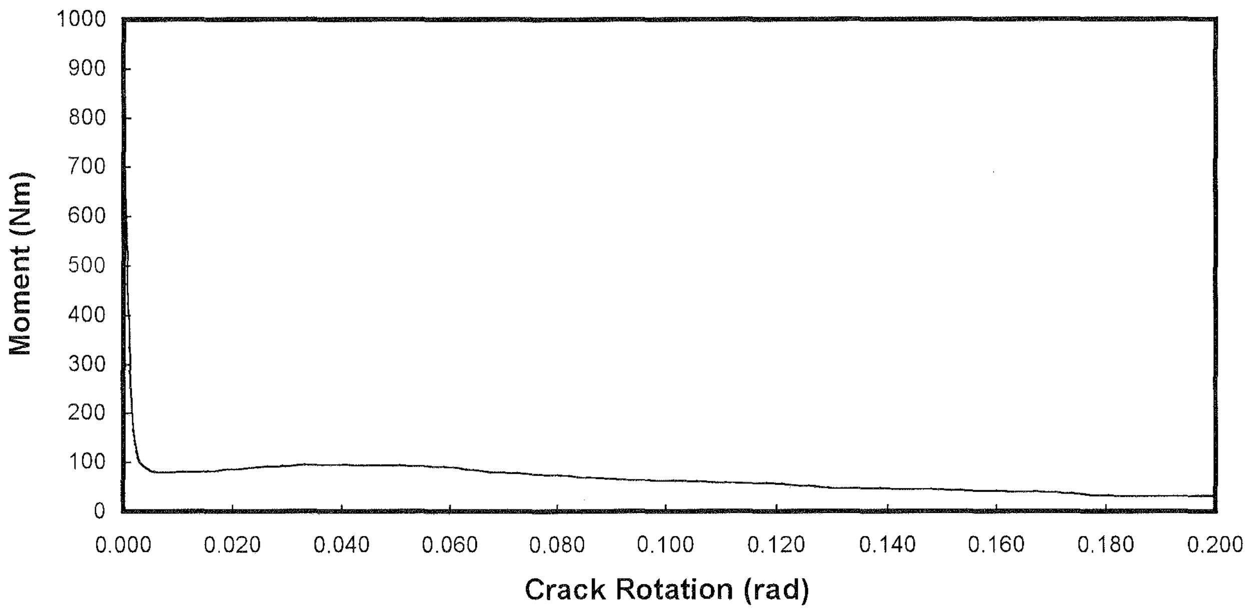
Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney, Nepean
Civic Engineering and Environment
Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests — **Date:** 31-Jan-01
Specimen: Vinh Crack Rotation Beam V4-C03 — **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	75.0	121.7	0	11	450 mm	Depth and width are measured adjacent to the crack after
Value 2	75.5	122.0	-6	16	**Section**	completion of test. Very few tests produce more than one
Value 3	74.4	123.5			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	75.0	122.4	-3.0	13.5	114648 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.52 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 5.06 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

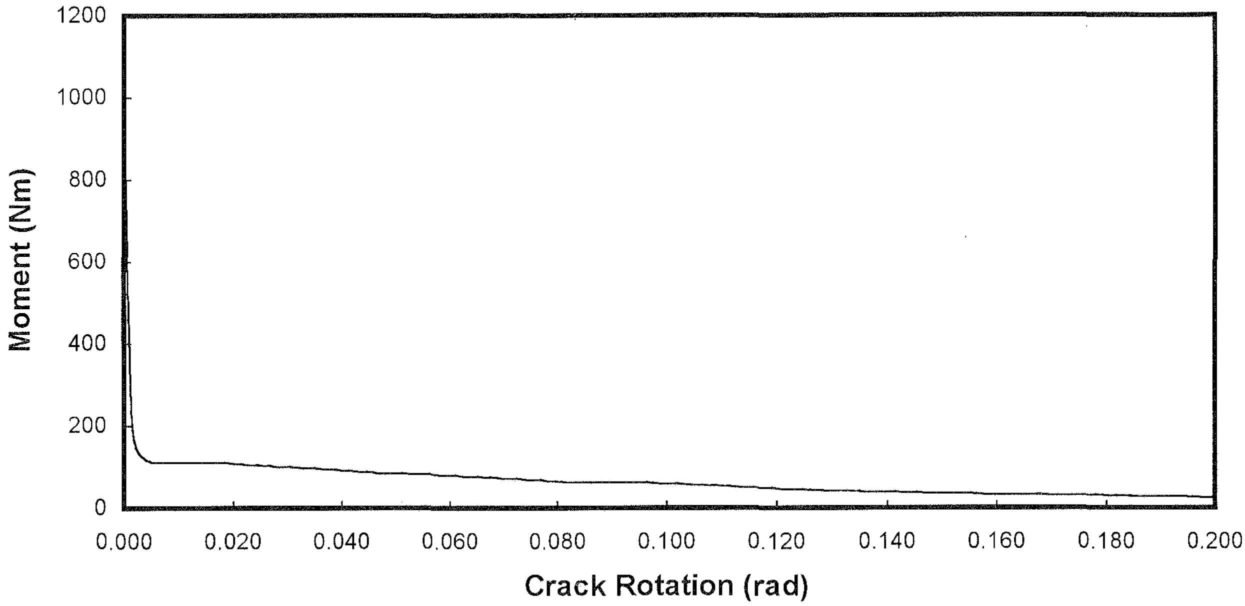
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests — **Date:** 31-Jan-01

Specimen: Vinh Crack Rotation Beam V4-C04 — **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	80.2	121.2	0	15	450 mm	Depth and width are measured adjacent to the crack after
Value 2	80.6	120.7	-5	10	**Section**	completion of test. Very few tests produce more than one
Value 3	79.0	122.5			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	79.9	121.5	-2.5	12.5	129349 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.54 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 5.87 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

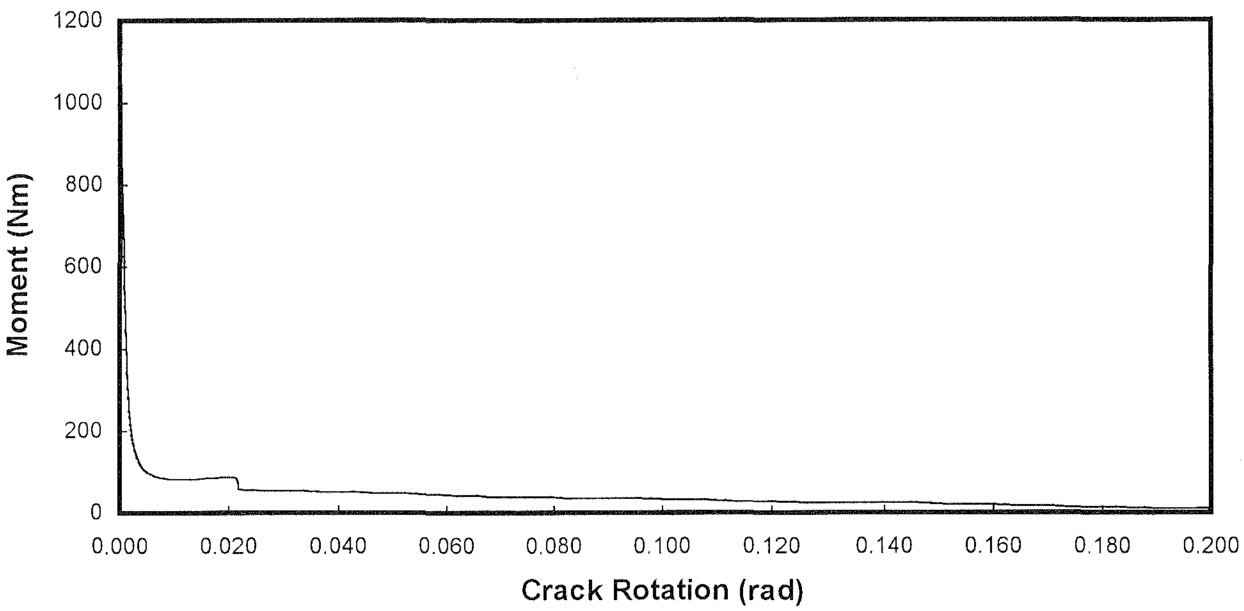
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests — **Date:** 31-Jan-01

Specimen: Vinh Crack Rotation Beam V4-C05 — **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	82.0	122.3	0	8	450 mm	Depth and width are measured adjacent to the crack after
Value 2	81.8	121.7	-13	0	**Section**	completion of test. Very few tests produce more than one
Value 3	83.4	122.6			**Modulus**	crack. Section Modulus is calculated as $Z=bd^2/6$, and is
Mean	82.4	122.2	-6.5	4.0	138285 mm^3	used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.59 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 4.44 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

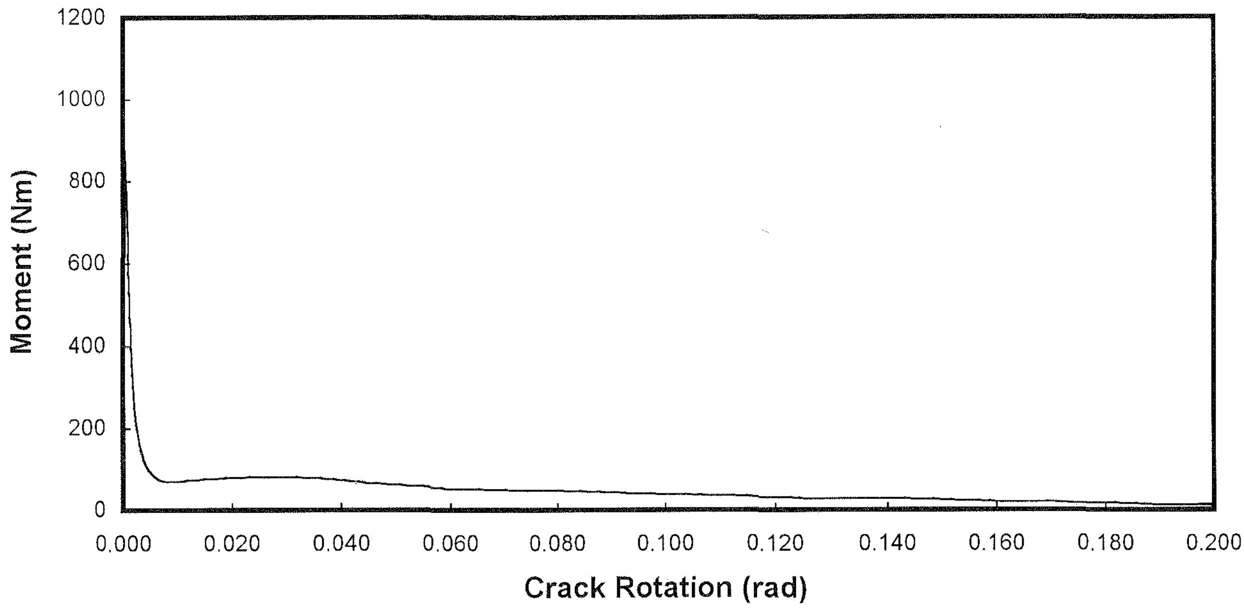
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 1-Feb-01

Specimen: Vinh Crack Rotation Beam V4-C06 **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	75.0	128.1	10	16	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	75.6	124.2	0	15	**Section Modulus**	
Value 3	77.7	122.9				
Mean	76.1	125.1	5.0	15.5	120715 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

8.62 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 5.07 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

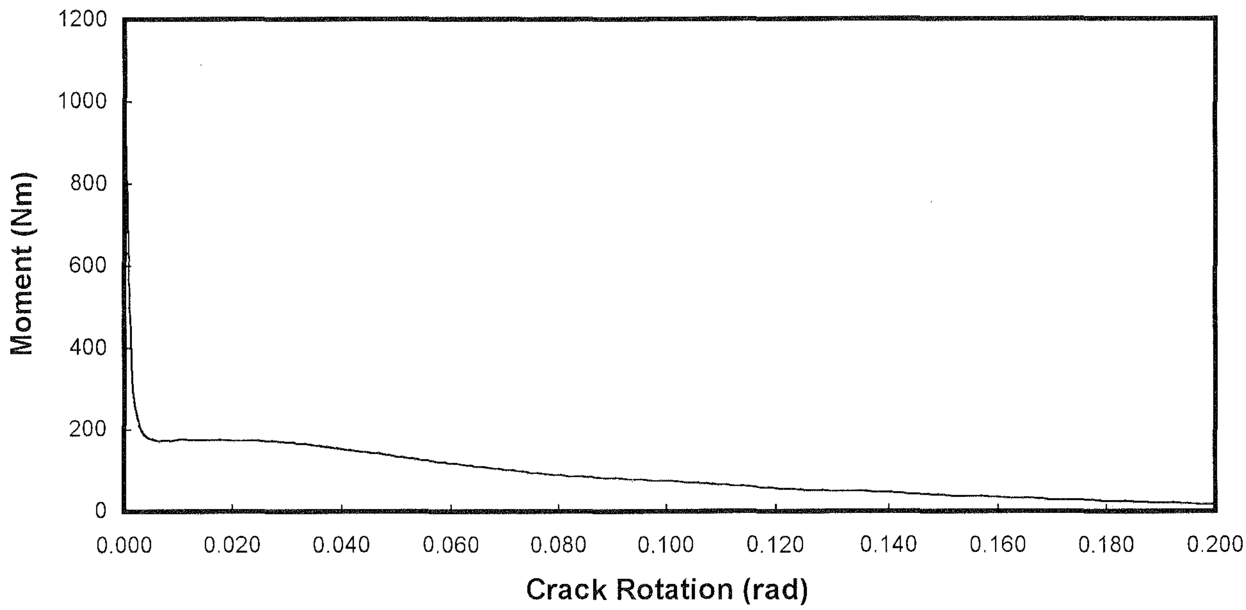
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 1-Feb-01

Specimen: Vinh Crack Rotation Beam V4-C07 **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	77.4	126.0	3	16	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	77.1	122.1	7	11	**Section Modulus**	
Value 3	73.0	126.3				
Mean	75.8	124.8	5.0	13.5	119614 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

8.92 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 9.22 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

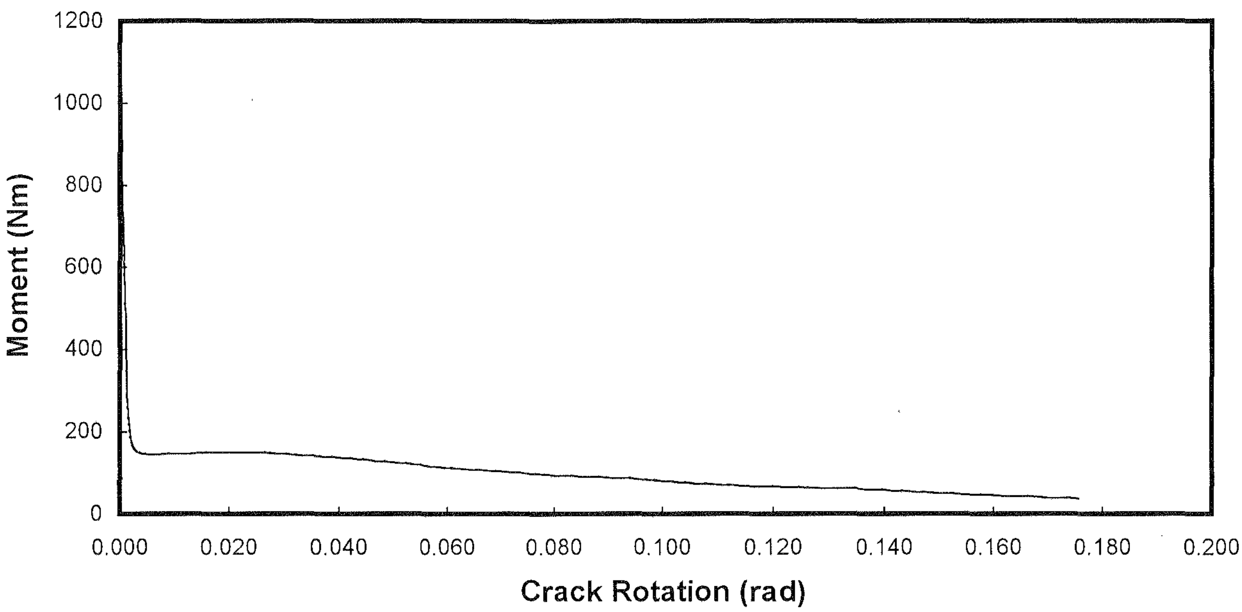
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 1-Feb-01

Specimen: Vinh Crack Rotation Beam V4-C08 **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	76.0	122.3	-6	22	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	77.3	122.4	-15	15	**Section Modulus**	
Value 3	76.9	125.0				
Mean	76.7	123.2	-10.5	18.5	120933 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

9.53 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 7.97 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

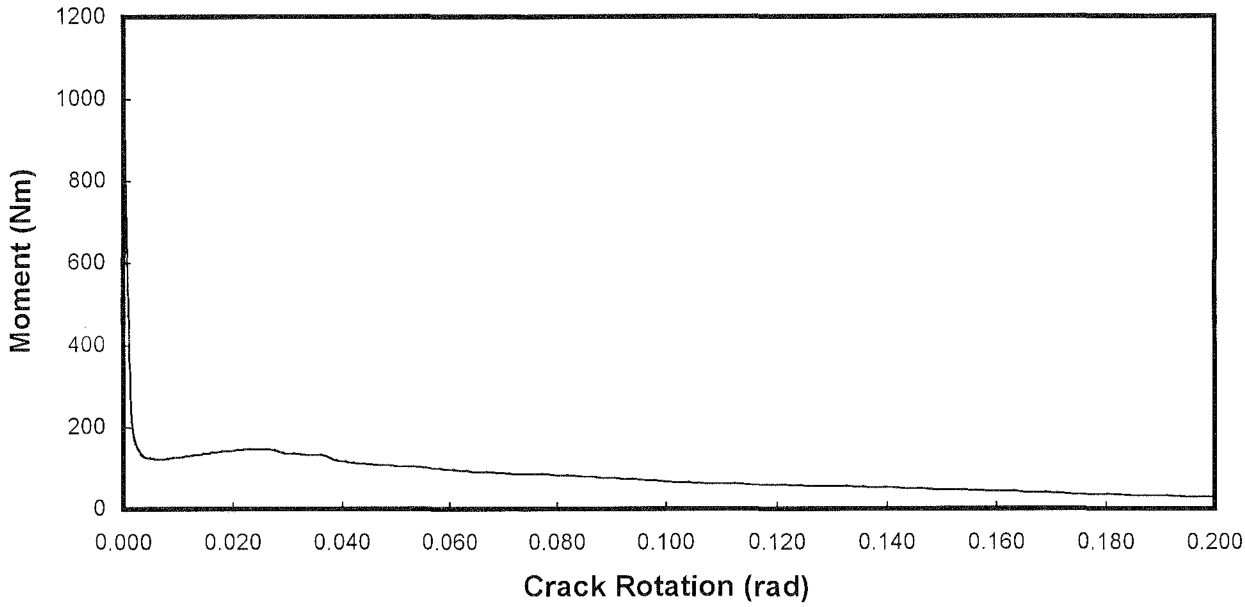
The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 1-Feb-01
Specimen: Vinh Crack Rotation Beam V4-C09 **Age:** 91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	78.8	127.2	-6	16	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	78.7	124.3	-2	14	**Section Modulus**	
Value 3	76.2	124.9				
Mean	77.9	125.5	-4.0	15.0	126897 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

8.50 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 7.25 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

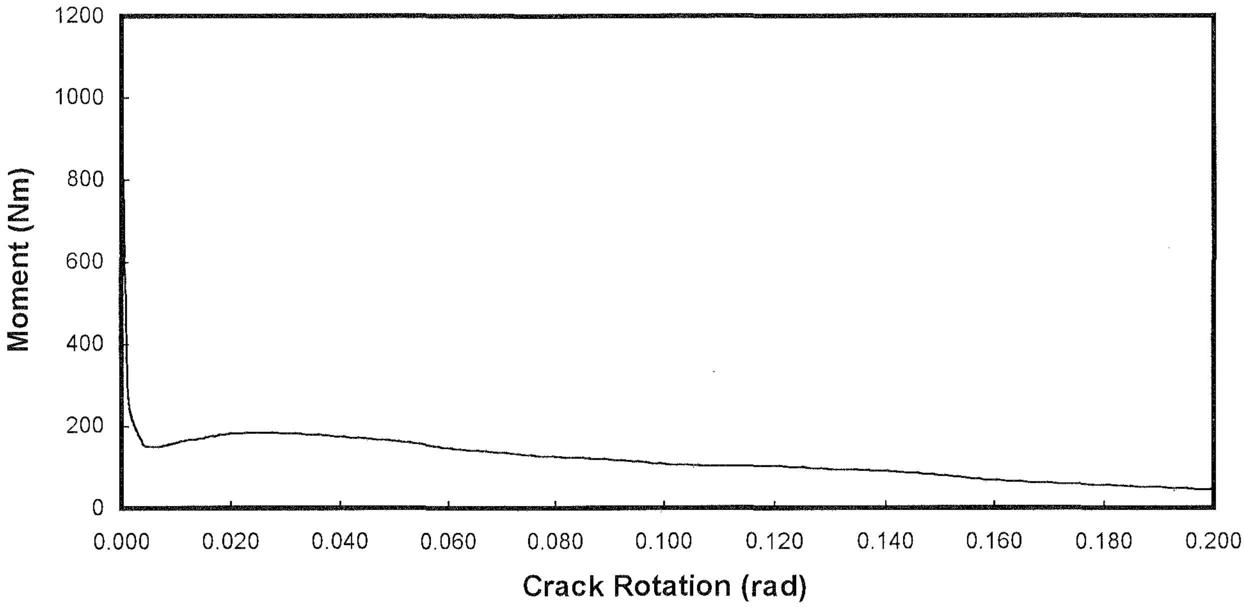
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: **Comparative Beam and Panel Tests** Date: **1-Feb-01**

Specimen: **Vinh Crack Rotation Beam V4-C10** Age: **91 days**



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	80.6	122.6	0	16	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	80.4	122.3	-15	22	**Section Modulus**	
Value 3	81.2	123.5				
Mean	80.7	122.8	-7.5	19.0	133399 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

8.29 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 9.27 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

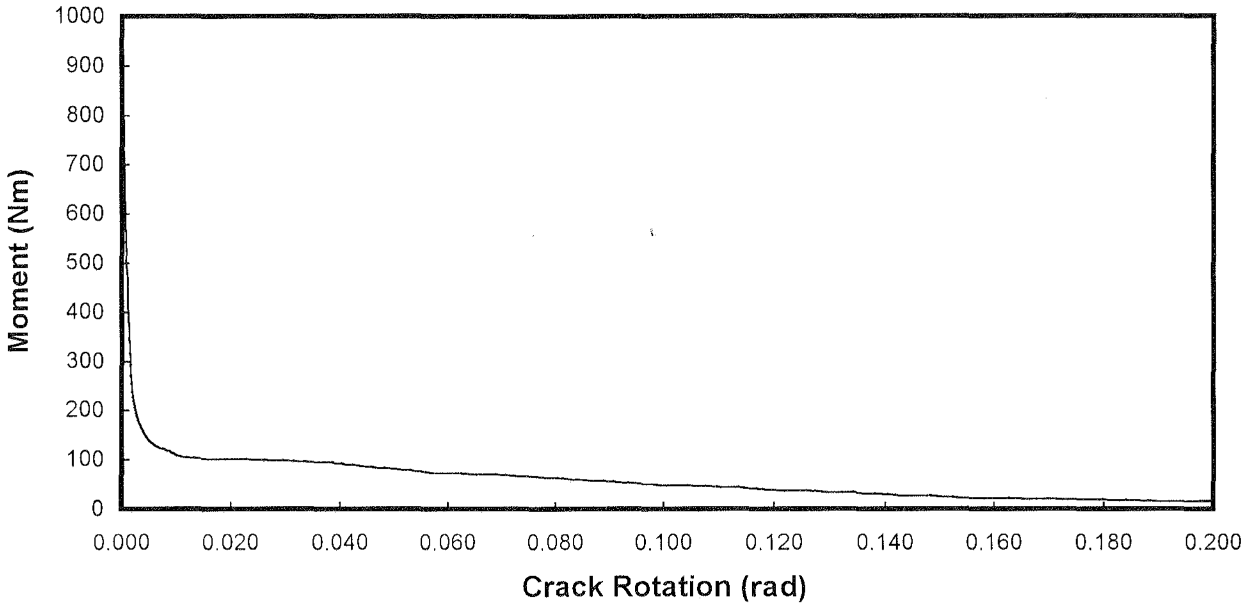
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests — **Date:** 1-Feb-01

Specimen: Vinh Crack Rotation Beam V4-C11 — **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	75.4	124.3	-9	17	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	75.0	123.7	-4	10	**Section Modulus**	
Value 3	75.1	125.2				
Mean	75.2	124.4	-6.5	13.5	117144 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

8.03 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 6.04 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

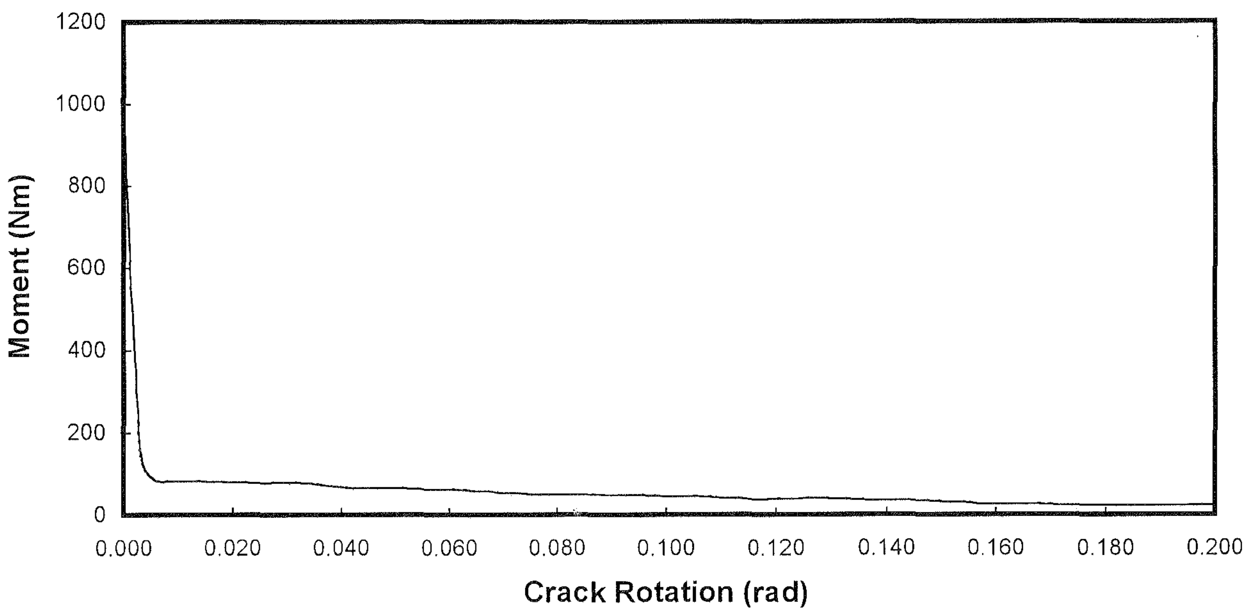
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests — **Date:** 1-Feb-01

Specimen: Vinh Crack Rotation Beam V4-C11 — **Age:** 91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span
Value 1	81.6	122.4	10	11	450 mm
Value 2	81.0	122.2	5	11	**Section Modulus**
Value 3	82.8	124.0			
Mean	81.8	122.9	7.5	11.0	137022 mm^3

Measurement and Calculation of Results

Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

7.96 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 5.30 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

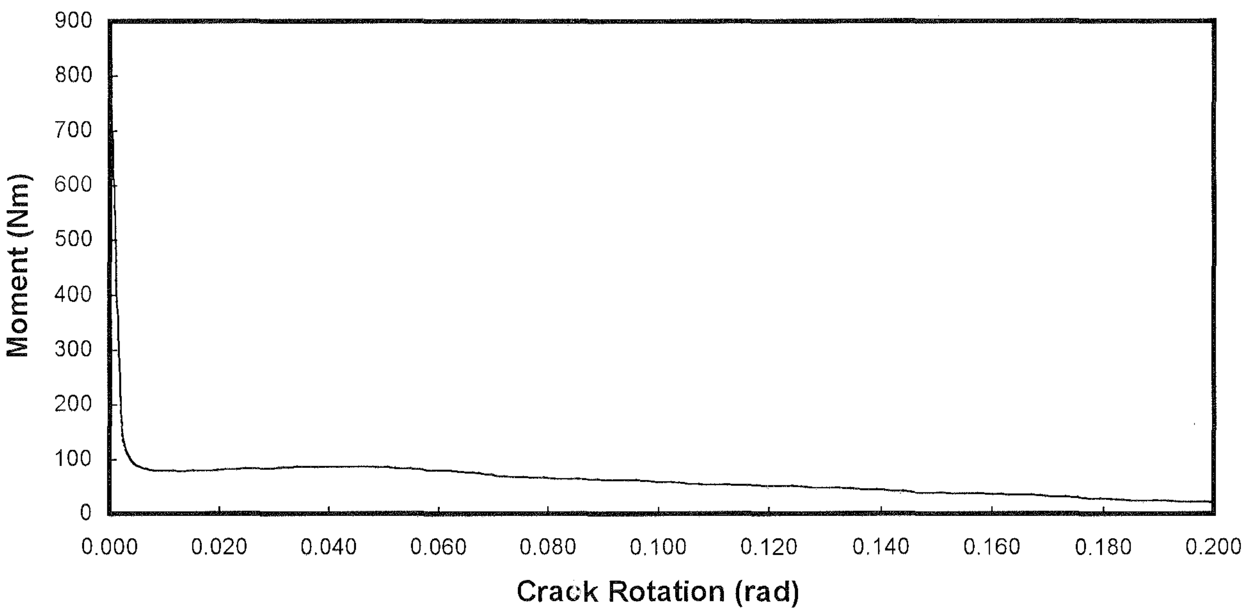
University of Western Sydney, Nepean

Civic Engineering and Environment

Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 1-Feb-01

Specimen: Vinh Crack Rotation Beam V4-C11 **Age:** 91 days



Dimensional Data

(All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	
Value 1	74.4	121.7	-29	13	450	mm
Value 2	75.0	121.5	-2	12	**Section Modulus**	
Value 3	74.2	121.7				
Mean	74.5	121.6	-15.5	12.5	112617	mm^3

Measurement and Calculation of Results

Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

8.34 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 5.25 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

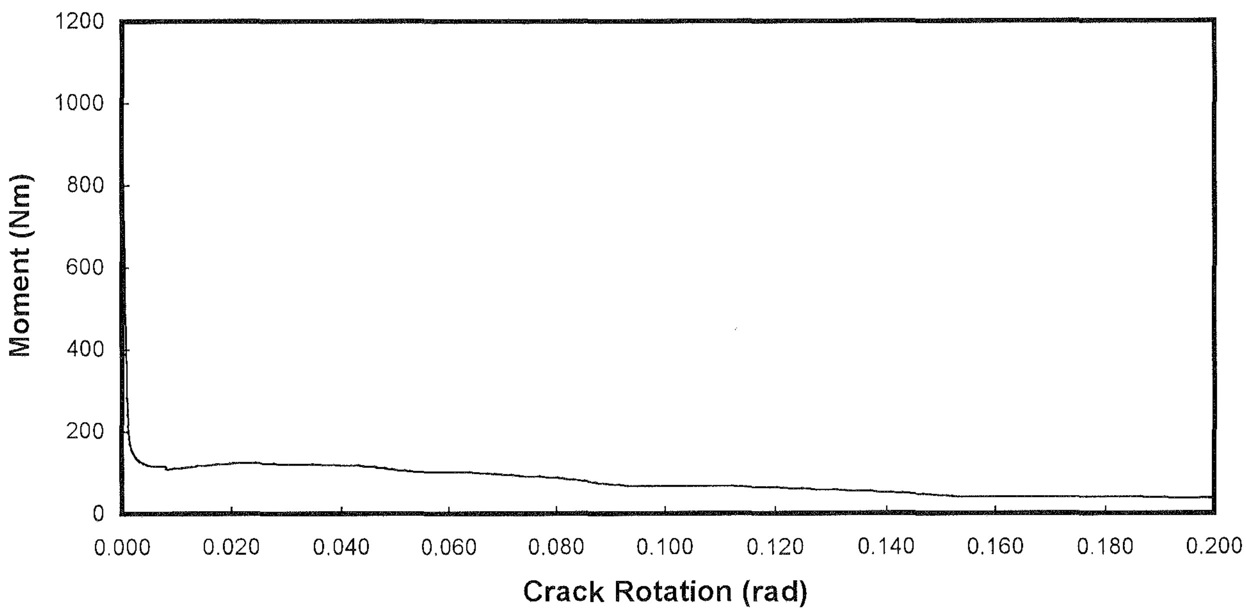
Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

University of Western Sydney, Nepean
Civic Engineering and Environment
Fibre Reinforced Concrete Beam Test Result

Client: Comparative Beam and Panel Tests **Date:** 1-Feb-01
Specimen: Vinh Crack Rotation Beam V4-C15 **Age:** 91 days



Dimensional Data (All dimensions in mm)

Quantity	Depth	Widths	Crack offsets	Fibres	Span	Measurement and Calculation of Results
Value 1	75.3	123.6	0	13	450 mm	Depth and width are measured adjacent to the crack after completion of test. Very few tests produce more than one crack. Section Modulus is calculated as $Z=bd^2/6$, and is used to find Modulus of Rupture.
Value 2	75.2	122.3	6	10	**Section**	
Value 3	75.1	122.7			**Modulus**	
Mean	75.2	122.9	3.0	11.5	115803 mm^3	

Crack offset represents the distance of each end of the crack from the centre of the beam. Positive indicates offset toward strain channel 1.

Lever arm to Strain 1 42 mm Lever arm to Strain 2 42 mm

Flexural Strength

8.53 MPa Modulus of Rupture

Toughness Assessment

Energy absorption per mm of crack width between point of cracking and 0.05 rad rotation 6.47 Joules
(for a normalised beam width of 125 mm)

Comments

Condition of Failed Specimen

Concrete matrix was moderately well compacted, many small bubbles.
Reoco Wavecut fibres were used in this set
Fibres were well distributed.

Supplementary Information on Specimen Preparation and Testing

Specimens had been trimmed to size from larger beams roughly cut from sprayed panels. All surfaces were smooth and even, although parallelism was not as good as can be expected from cast specimens. Test machine rollers could be properly seated at the start of each test, as rollers sat flat on the upper and lower surfaces. Lower rollers were torsion-free, upper roller was fixed against rotation.

The test was carried out under open-loop (displacement) control in an Instron 6027 with 5500 controller and Merlin software. Displacement was measured with two end-mounted LVDT's that eliminated all extraneous displacements from the data record. The stiffness of the Instron frame was claimed by the manufacturer to be 400 kN/mm, but the stiffness of the frame with loadcell and fixtures included was measured to be 75 kN/mm.

2.2. Experimental Results of the RD Panel Tests

2.2.1. Concrete Set 1

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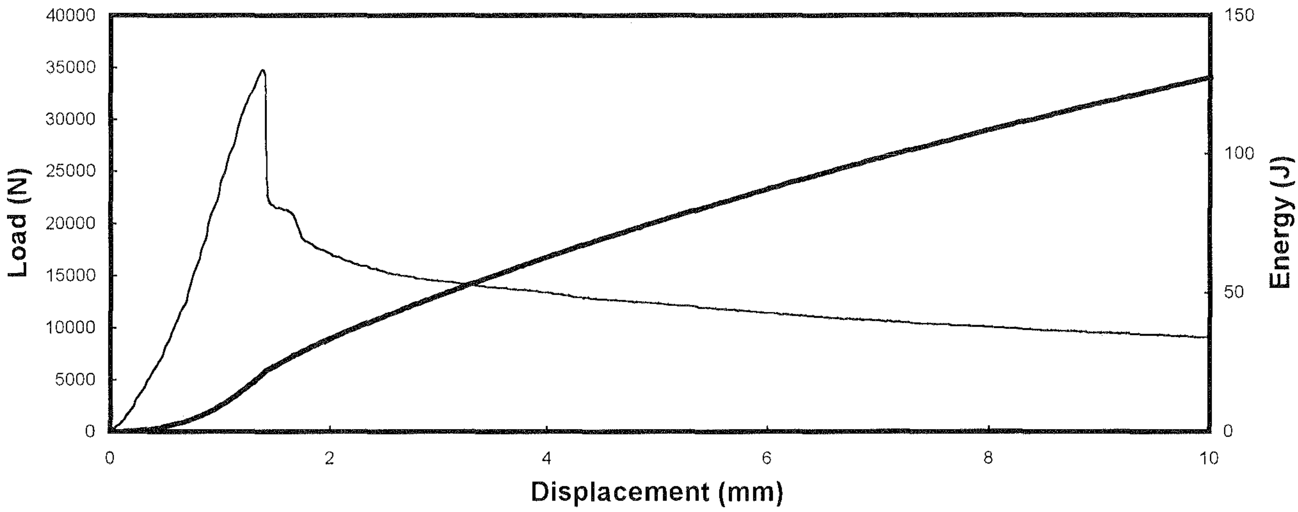
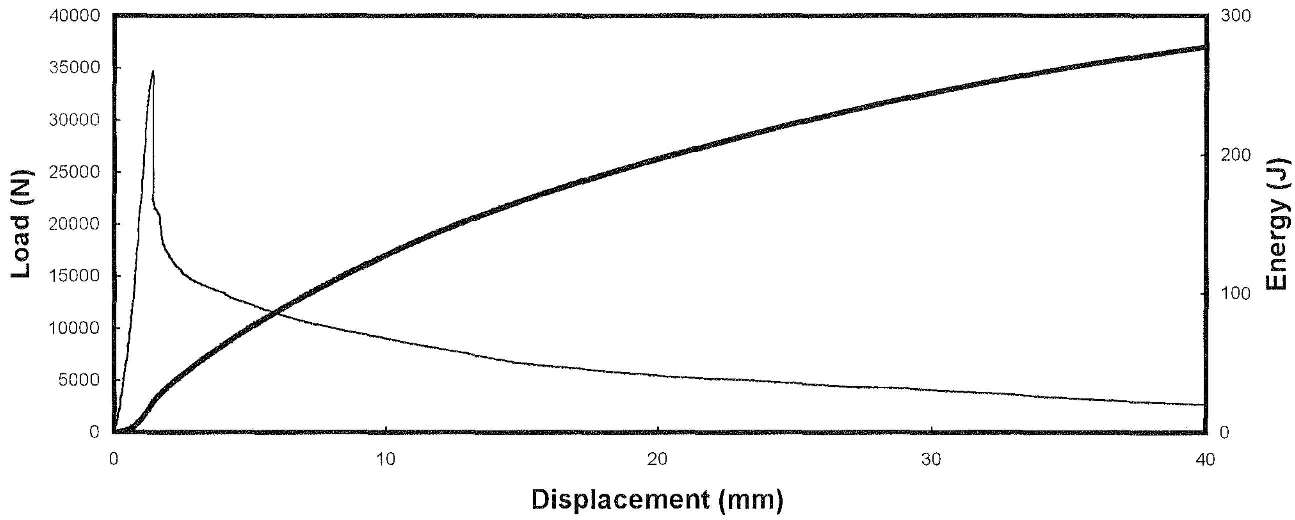
Round Determinate Panel Test Result **Specimen ID:** V1-D01

Set: V1 Panel Set **Age:** 56 days **Date:** 1/15/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
800	14	79
803	9	78
804	16	77
	6	78
	22	79
mean: 802.3	22	76
	20	74
	26	78
	16	77
	21	75
	x: 17.2	77.1
	cov: 36.3	2.2

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**34806** N	**32840** N
Energy at 5 mm	**75** J	**71** J
Energy at 10 mm	**127** J	**121** J
Energy at 20 mm	**197** J	**187** J
Energy at 40 mm	**277** J	**265** J

Performance corrections carried out according to Bernard and Pircher (2000)

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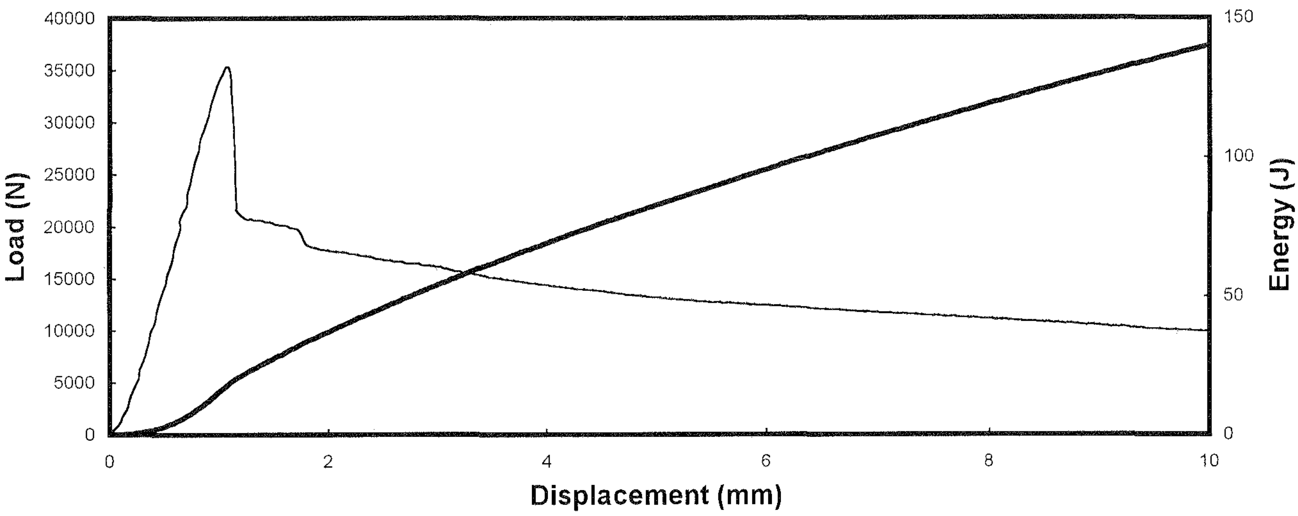
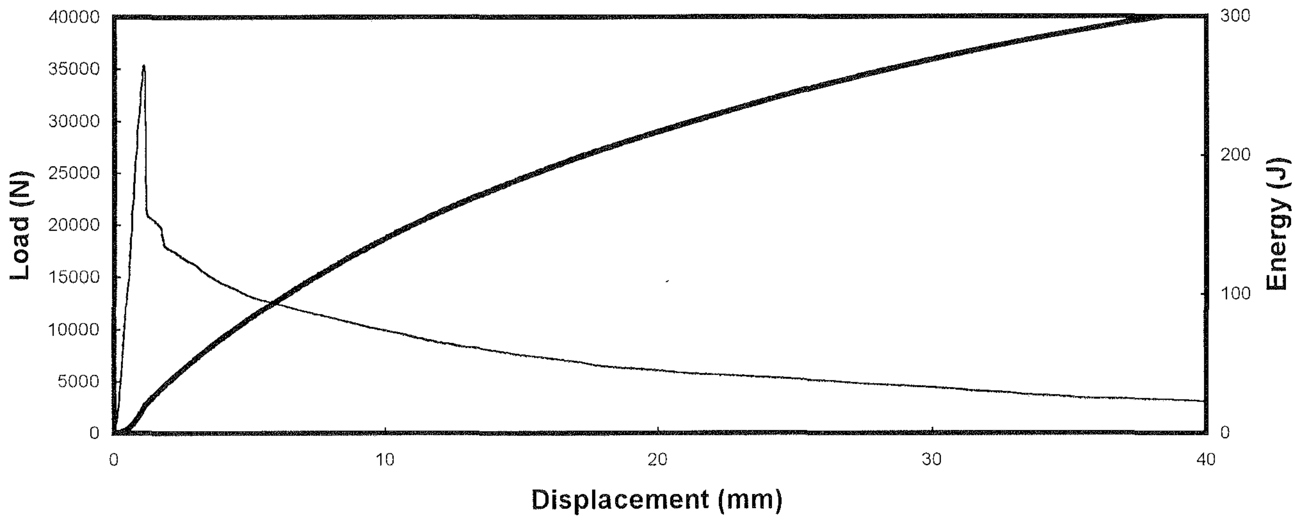
Round Determinate Panel Test Result **Specimen ID:** V1-D02

Set: V1 Panel Set **Age:** 56 days **Date:** 1/15/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
807	22	80
806	16	81
805	12	79
	10	80
	14	81
mean: 806.0	19	75
	17	77
	13	80
	15	78
	14	78
x:	15.2	78.9
cov:	23.0	2.4

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	35392 N	31741 N
Energy at 5 mm	82 J	74 J
Energy at 10 mm	140 J	126 J
Energy at 20 mm	217 J	197 J
Energy at 40 mm	305 J	281 J

Performance corrections carried out according to Bernard and Pircher (2000)

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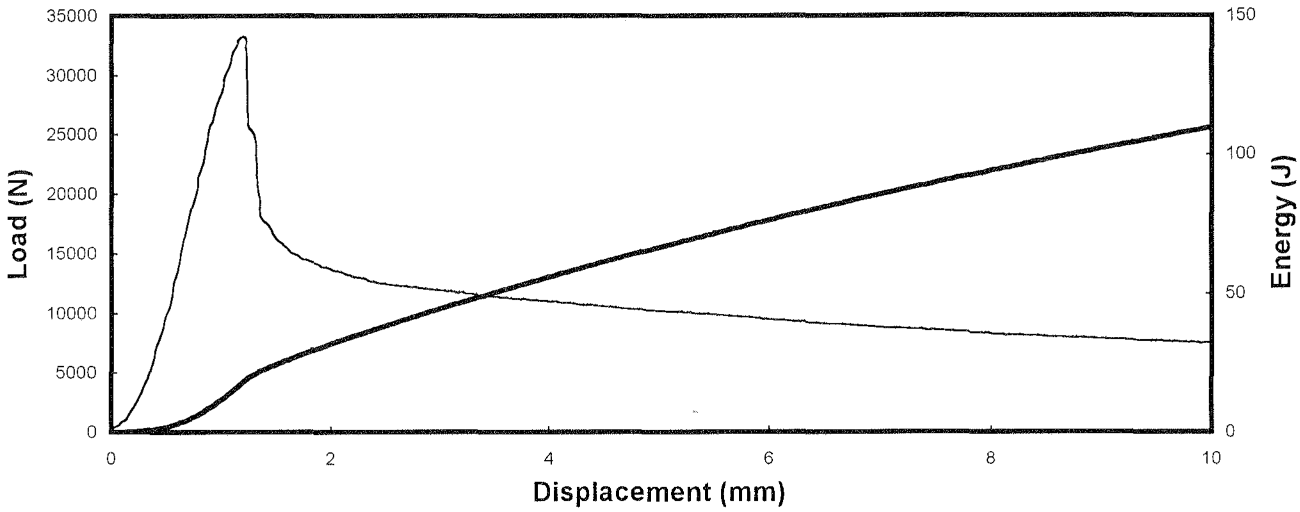
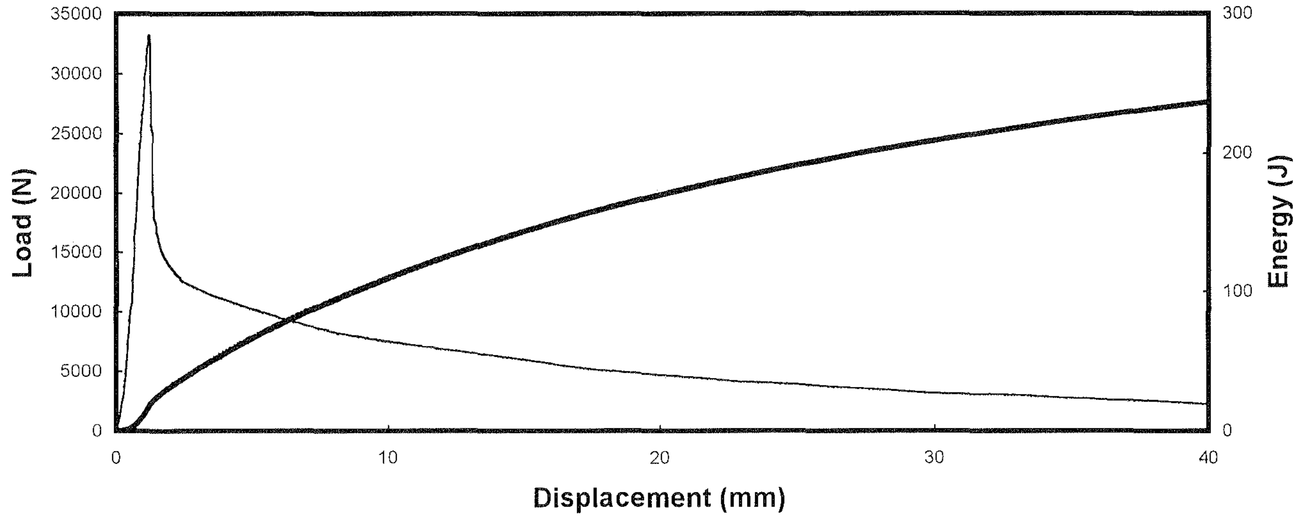
Round Determinate Panel Test Result — **Specimen ID:** V1-D03

Set: V1 Panel Set — **Age:** 56 days **Date:** 1/15/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
805	18	80
802	17	80
804	20	80
	11	80
	13	80
mean: 803.7	18	75
	16	75
	12	75
	15	77
	14	76
x:	15.4	77.8
cov:	18.9	3.1

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	33281 N	30788 N
Energy at 5 mm	66 J	61 J
Energy at 10 mm	110 J	102 J
Energy at 20 mm	170 J	158 J
Energy at 40 mm	236 J	223 J

Performance corrections carried out according to Bernard and Pircher (2000)

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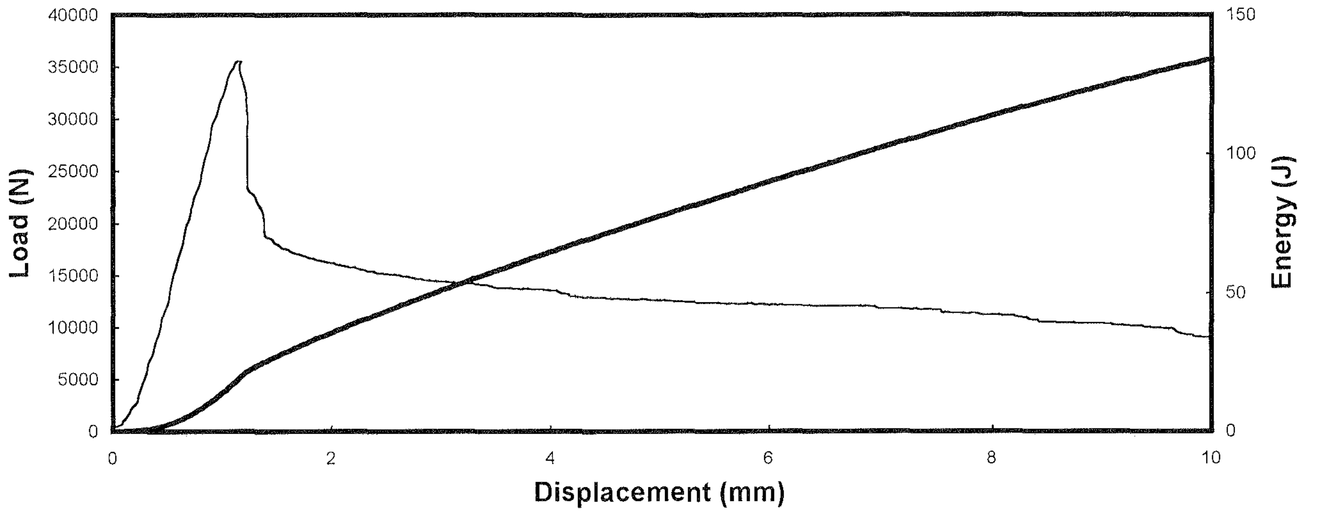
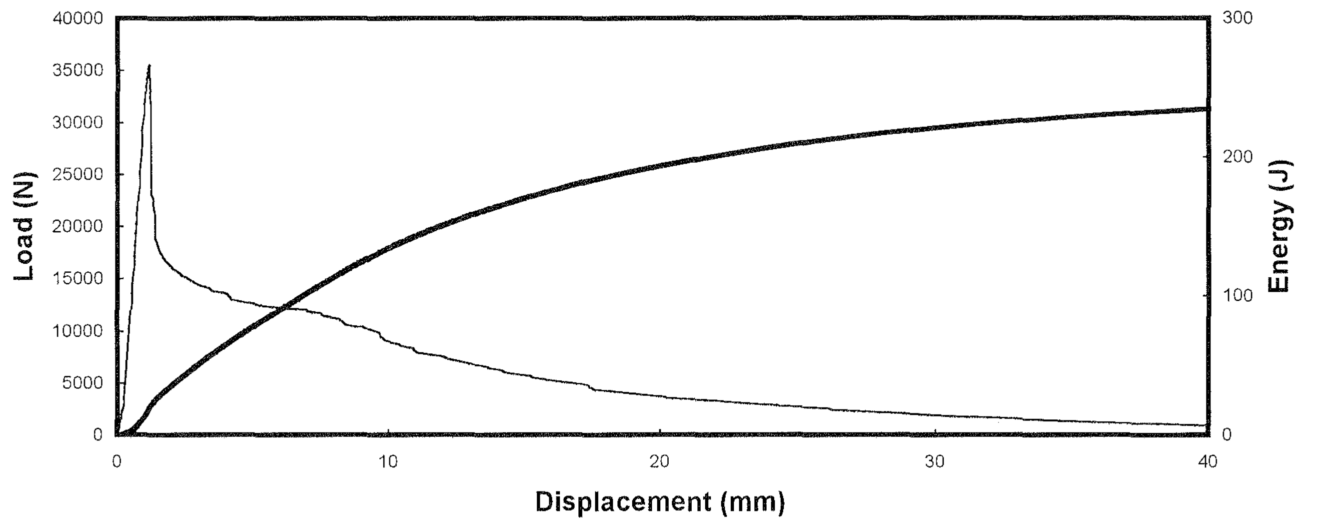
Round Determinate Panel Test Result **Specimen ID:** V1-D04

Set: V1 Panel Set **Age:** 56 days **Date:** 1/15/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
806	9	82
802	9	82
807	16	81
	18	84
	14	84
mean: 805.0	11	78
	11	76
	11	80
	14	78
	7	76
	x: 12	80.1
	cov: 28.6	3.7

Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**35564** N	**30986** N
Energy at 5 mm	**77** J	**68** J
Energy at 10 mm	**134** J	**118** J
Energy at 20 mm	**193** J	**171** J
Energy at 40 mm	**234** J	**211** J

Performance corrections carried out according to Bernard and Pircher (2000)

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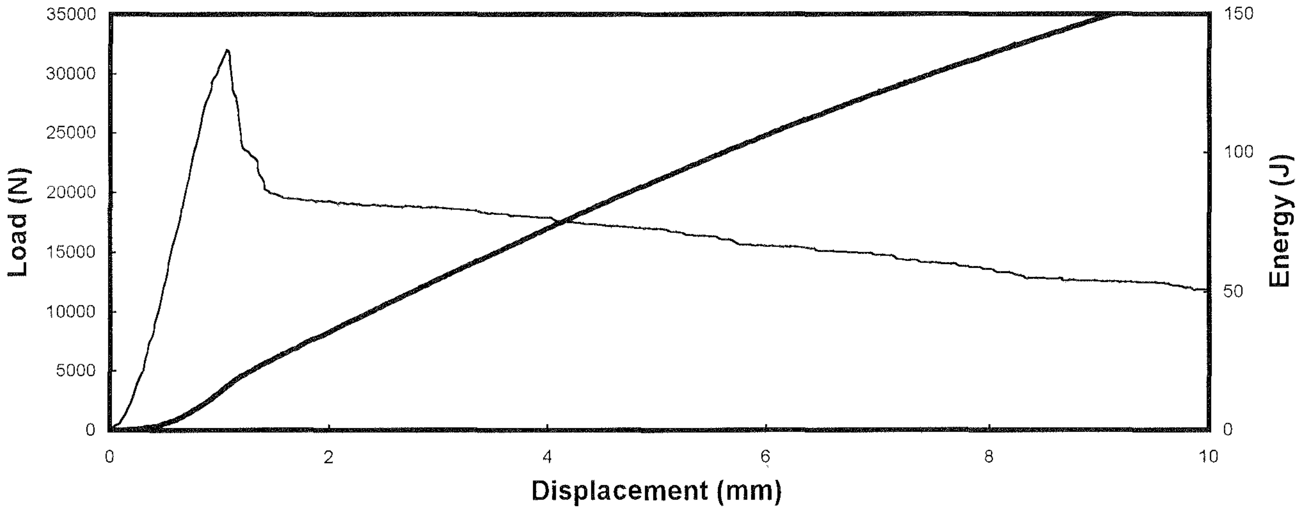
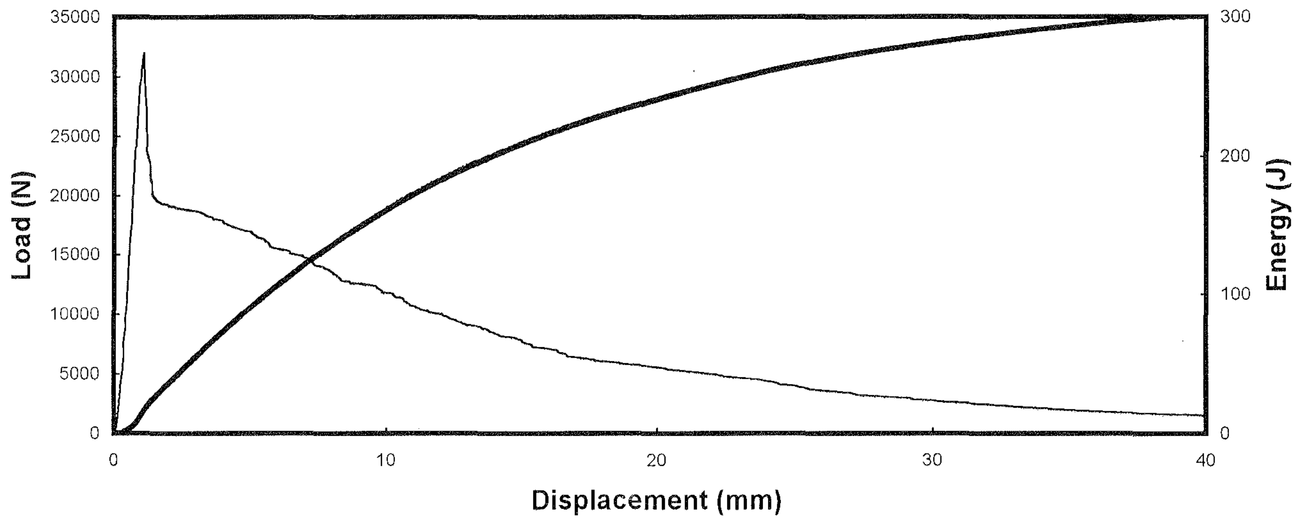
Round Determinate Panel Test Result **Specimen ID:** V1-D05

Set: V1 Panel Set **Age:** 56 days **Date:** 1/15/01





Specimen Dimensions

Diameter (mm)		Fibres	Thickness (mm)
796		16	76
798		14	77
800		18	76
		9	76
		16	76
mean: 798.0		8	76
		10	74
		13	75
		13	77
		15	75
	x:	13.2	75.8
	cov:	24.9	1.2

Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	32024 N	31430 N
Energy at 5 mm	90 J	88 J
Energy at 10 mm	161 J	158 J
Energy at 20 mm	241 J	237 J
Energy at 40 mm	302 J	298 J

Performance corrections carried out according to Bernard and Pircher (2000)

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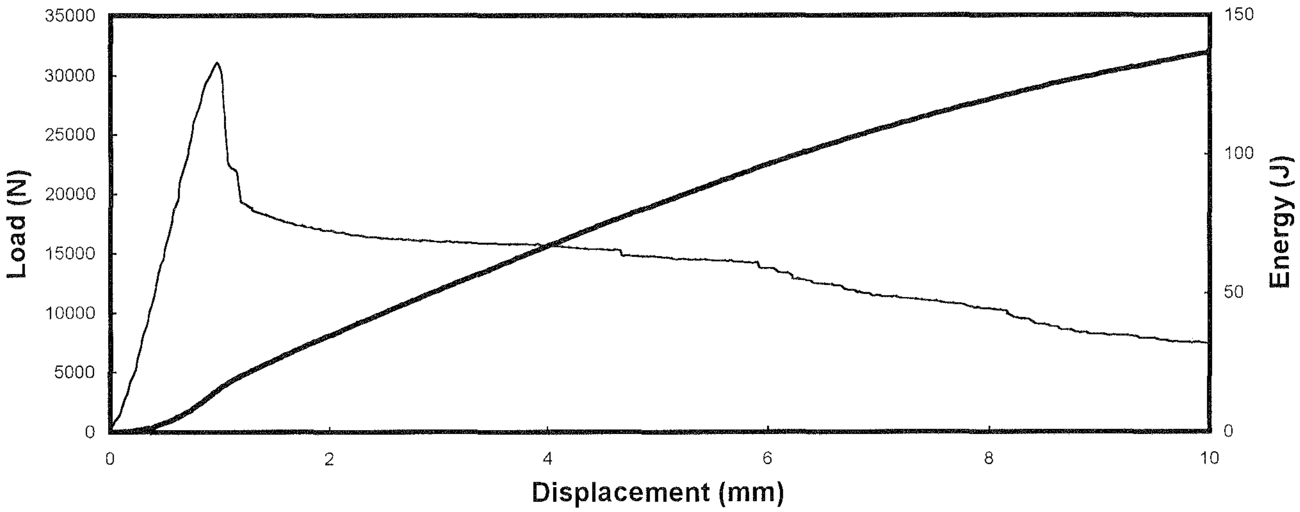
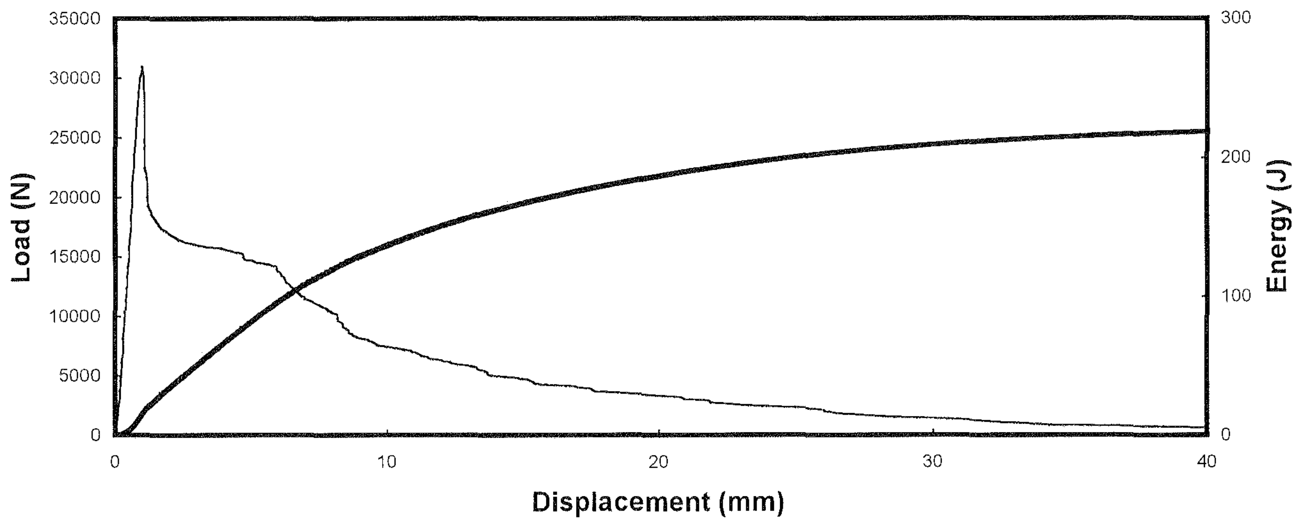
Round Determinate Panel Test Result **Specimen ID:** V1-D06

Set: V1 Panel Set **Age:** 56 days **Date:** 1/15/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
803	9	75
806	14	76
802	13	75
	11	76
	9	76
mean: 803.7	11	75
	9	77
	8	78
	13	75
	7	74
	x: 10.4	75.7
	cov: 22.8	1.5

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**31025** N	**30315** N
Energy at 5 mm	**82** J	**80** J
Energy at 10 mm	**137** J	**134** J
Energy at 20 mm	**186** J	**183** J
Energy at 40 mm	**218** J	**214** J

Performance corrections carried out according to Bernard and Pircher (2000)

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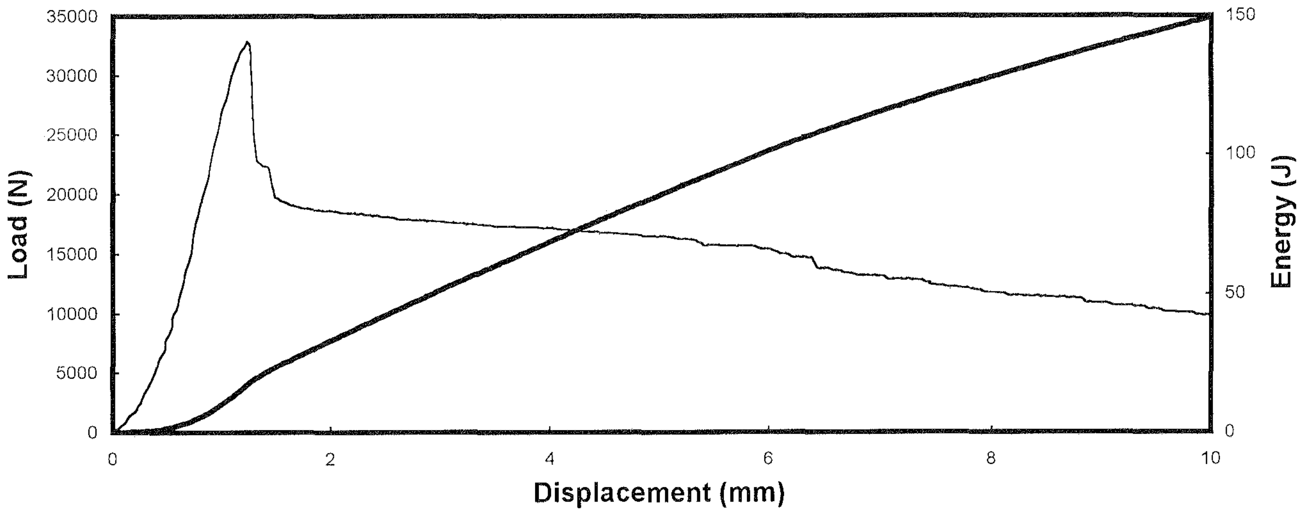
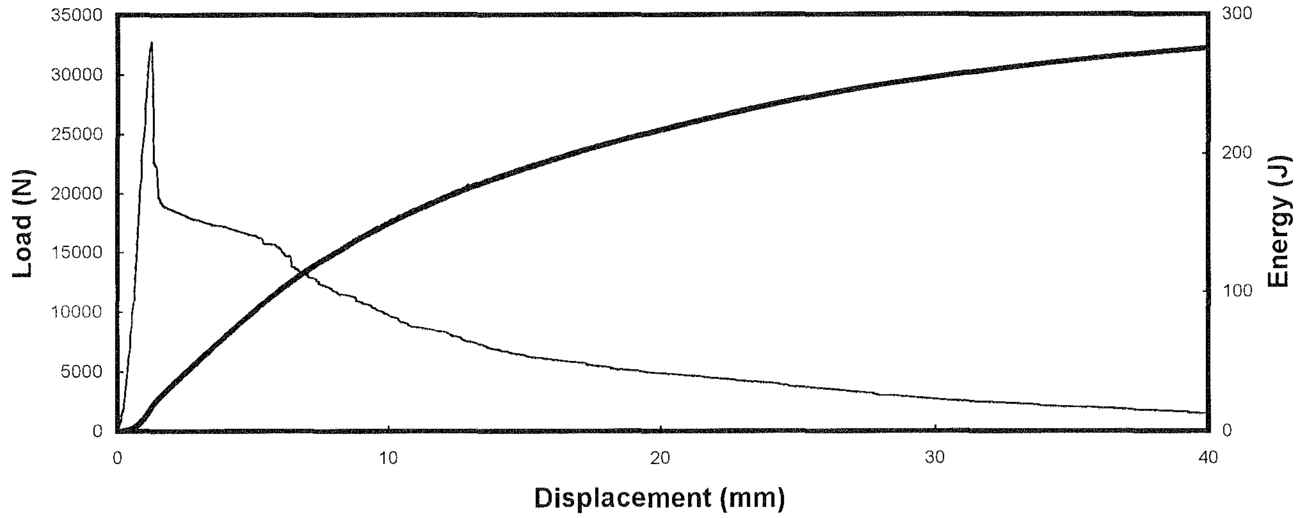
Round Determinate Panel Test Result

Specimen ID: V1-D07

Set: V1 Panel Set

Age: 56 days **Date:** 1/15/01





Specimen Dimensions

	Diameter (mm)	Fibres	Thickness (mm)
	803	12	77
	800	11	77
	803	11	77
		9	78
		14	77
mean:	802.0	5	76
		10	78
		11	75
		18	75
		17	75
x:		11.8	76.5
cov:		32.2	1.5

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**32825** N	**31472** N
Energy at 5 mm	**85** J	**82** J
Energy at 10 mm	**149** J	**143** J
Energy at 20 mm	**217** J	**209** J
Energy at 40 mm	**276** J	**267** J

Performance corrections carried out according to Bernard and Pircher (2000)

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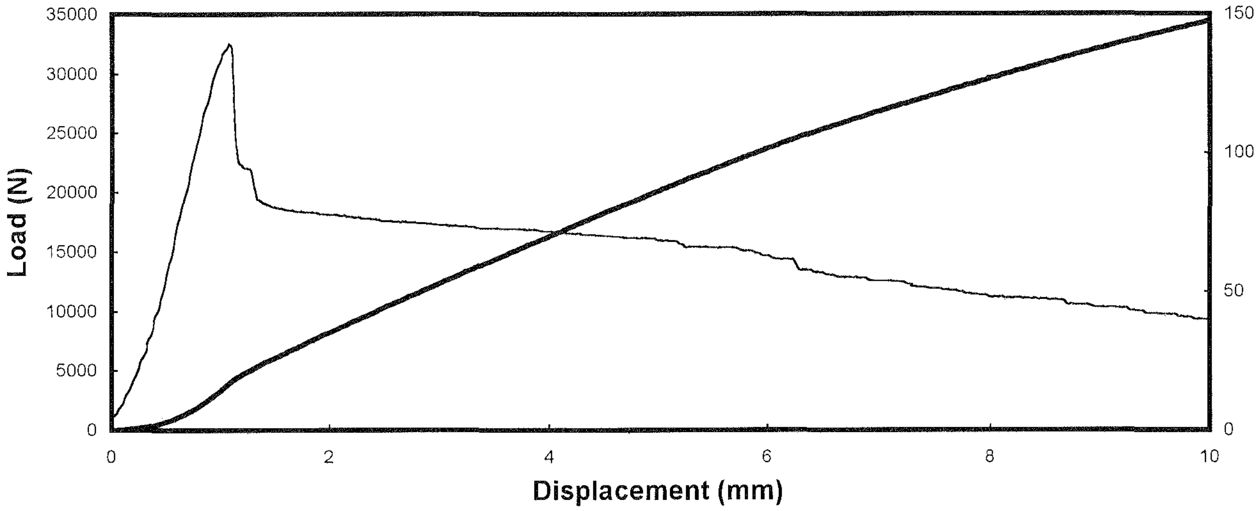
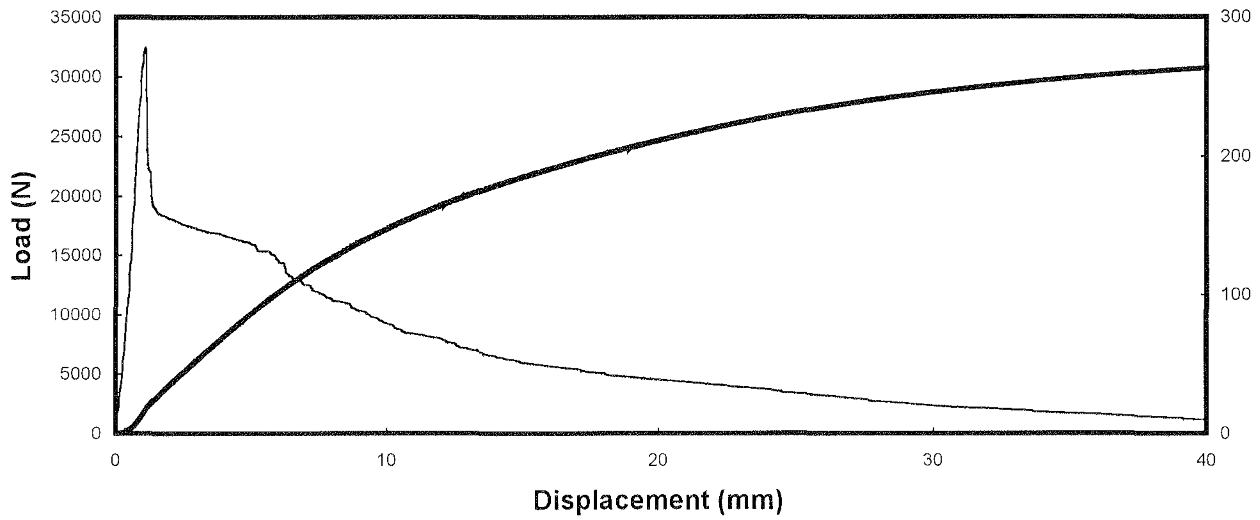
Round Determinate Panel Test Result **Specimen ID:** V1-D08

Set: V1 Panel Set **Age:** 56 days **Date:** 1/15/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
800	7	76
801	10	76
798	22	75
	17	77
	9	76
mean: 799.7	12	78
	24	77
	15	75
	17	78
	16	78
	x: 14.9	76.6
	cov: 37.0	1.5

Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.

Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**32506** N	**31175** N
Energy at 5 mm	**86** J	**83** J
Energy at 10 mm	**147** J	**142** J
Energy at 20 mm	**211** J	**203** J
Energy at 40 mm	**263** J	**255** J

Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney

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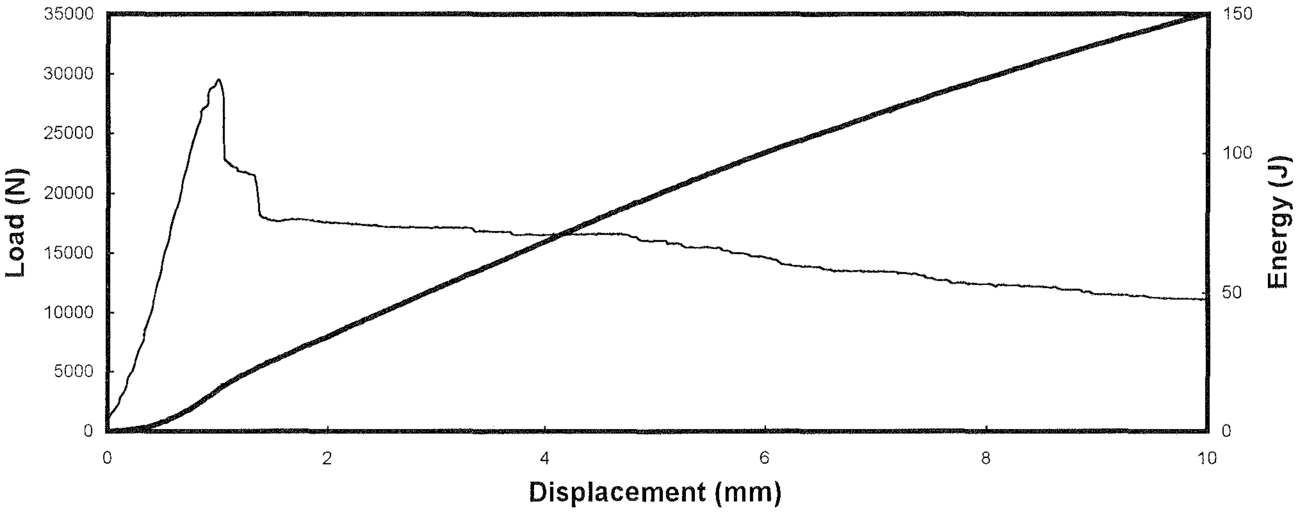
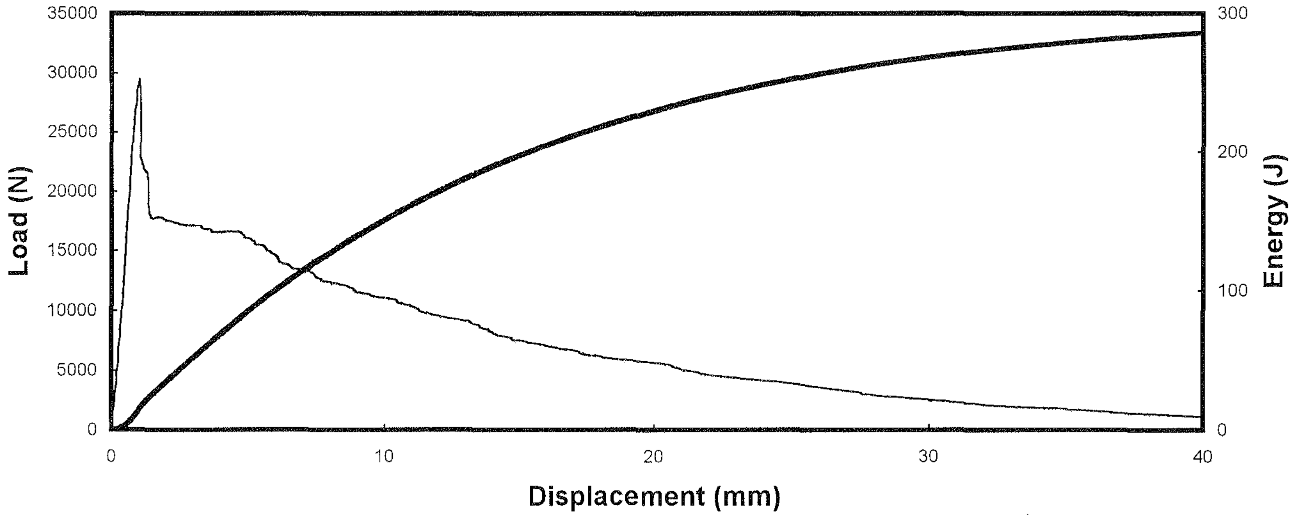
Round Determinate Panel Test Result **Specimen ID:** V1-D09

Set: V1 Panel Set **Age:** 56 days **Date:** 1/15/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
799	14	73
798	14	73
797	11	72
	7	72
	10	72
mean: 798.0	17	76
	7	75
	20	77
	26	77
	13	75
	x: 13.9	74.2
	cov: 42.4	2.8

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

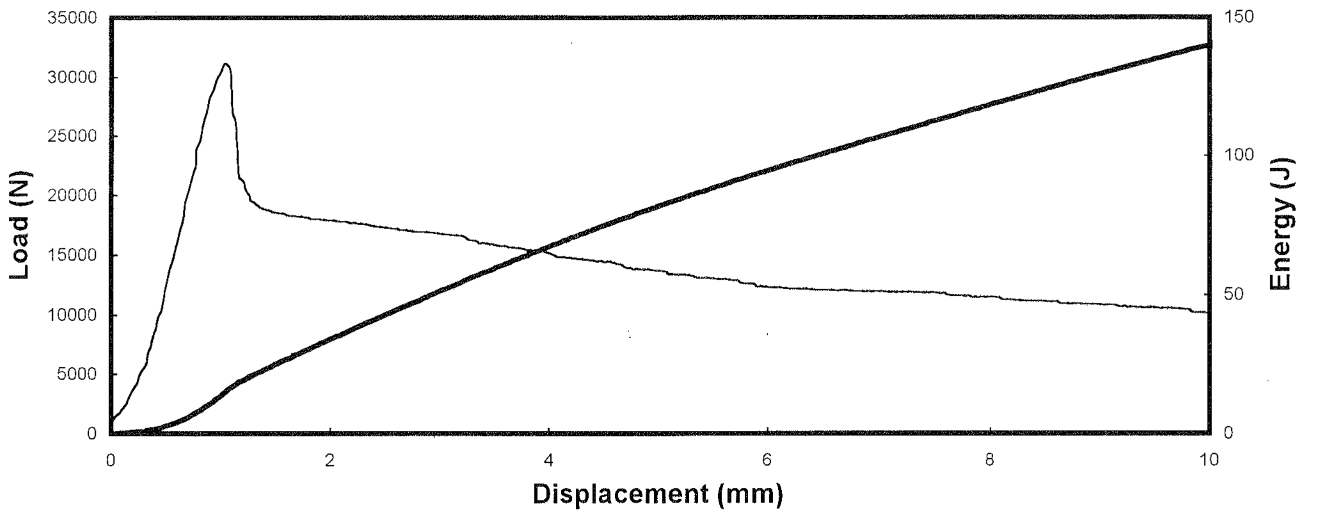
Parameter	Raw Results	Corrected
Peak Load (N)	**29517** N	**30233** N
Energy at 5 mm	**84** J	**86** J
Energy at 10 mm	**150** J	**154** J
Energy at 20 mm	**229** J	**234** J
Energy at 40 mm	**286** J	**291** J

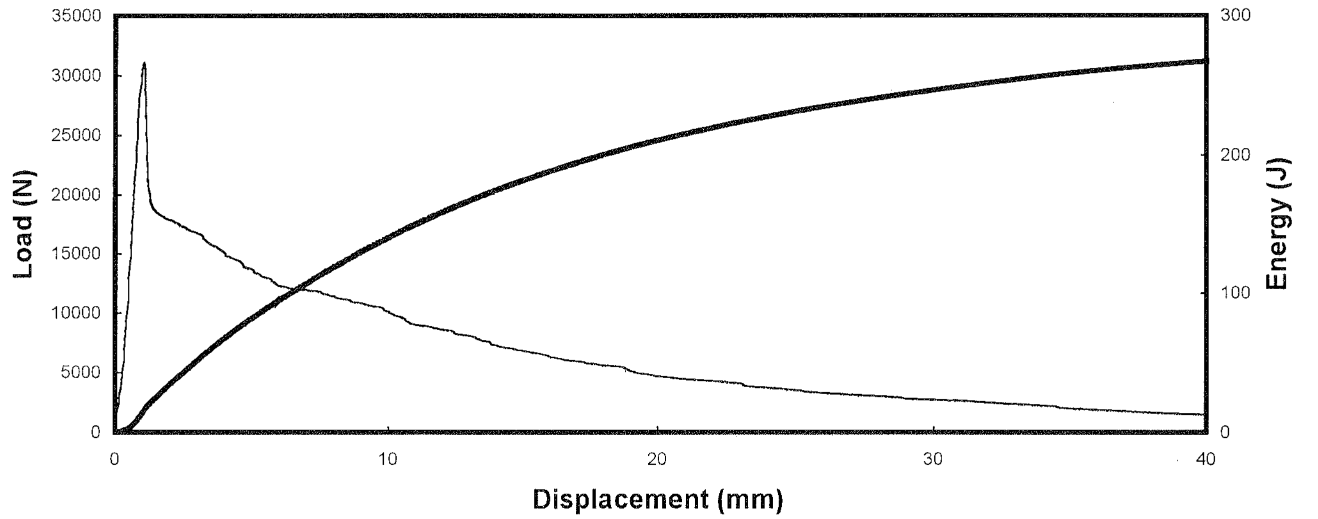
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V1-D10

Set: V1 Panel Set **Age:** 56 days **Date:** 1/15/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
801	14	76
805	23	76
803	8	76
	23	77
	16	77
mean: 803.0	9	75
	8	75
	12	78
	15	77
	15	77
x:	14.3	76.4
cov:	38.2	1.3

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

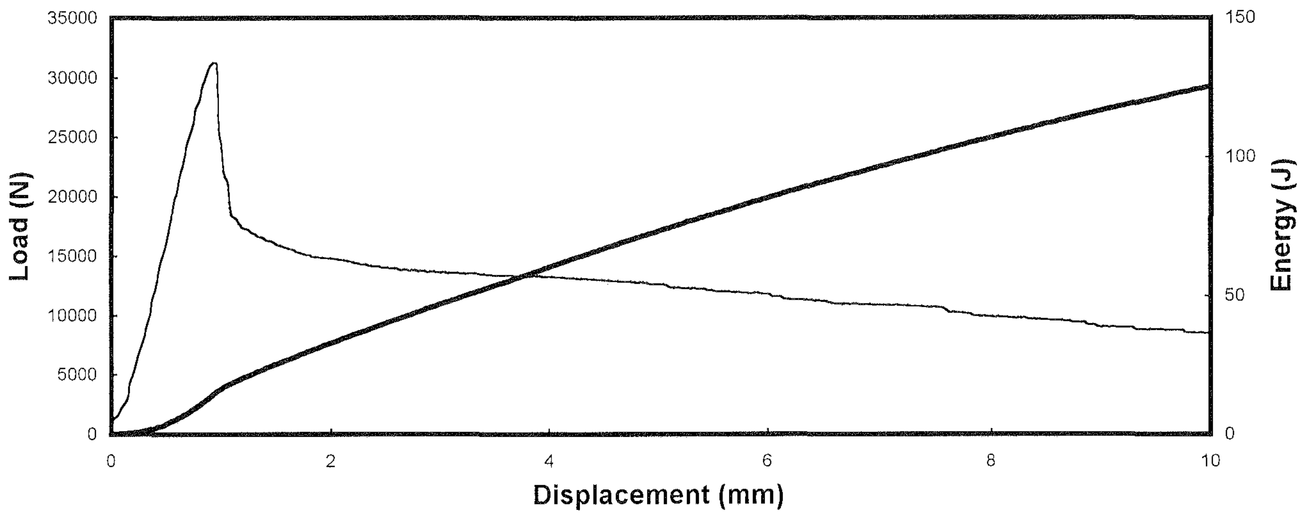
Parameter	Raw Results	Corrected
Peak Load (N)	31120 N	29877 N
Energy at 5 mm	81 J	78 J
Energy at 10 mm	140 J	135 J
Energy at 20 mm	210 J	203 J
Energy at 40 mm	267 J	259 J

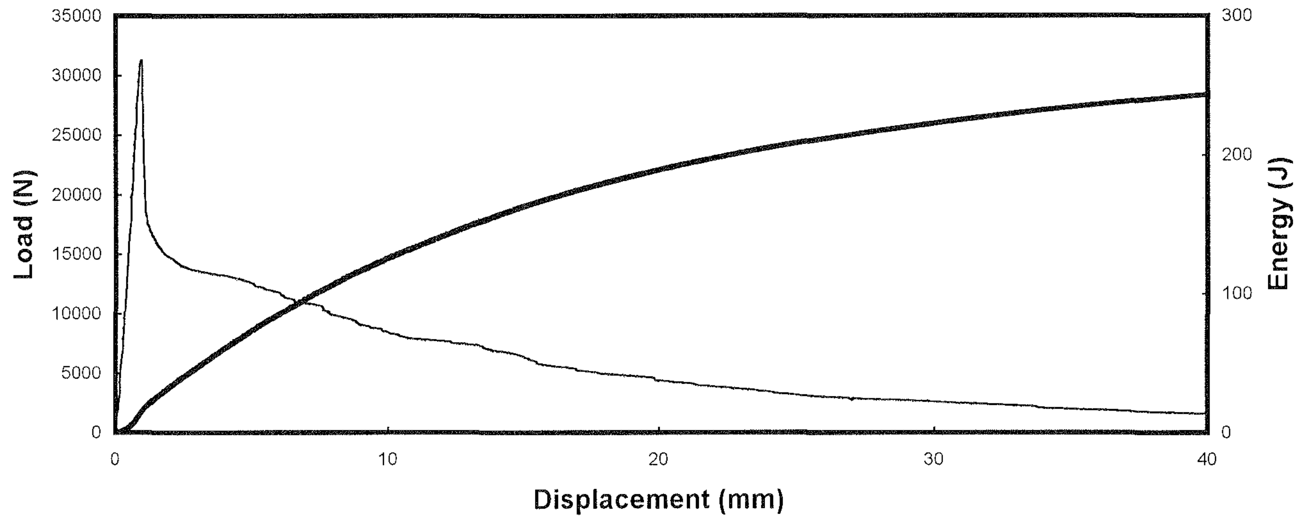
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V1-D11

Set: V1 Panel Set **Age:** 56 days **Date:** 1/15/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
799	13	77
800	14	76
797	8	77
	10	77
	13	77
mean: 798.7	15	75
	15	76
	17	77
	20	77
	16	75
	x: 14.1	76.4
	cov: 24.2	1.1

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**31300** N	**30214** N
Energy at 5 mm	**73** J	**70** J
Energy at 10 mm	**125** J	**121** J
Energy at 20 mm	**189** J	**183** J
Energy at 40 mm	**243** J	**237** J

Performance corrections carried out according to Bernard and Pircher (2000)

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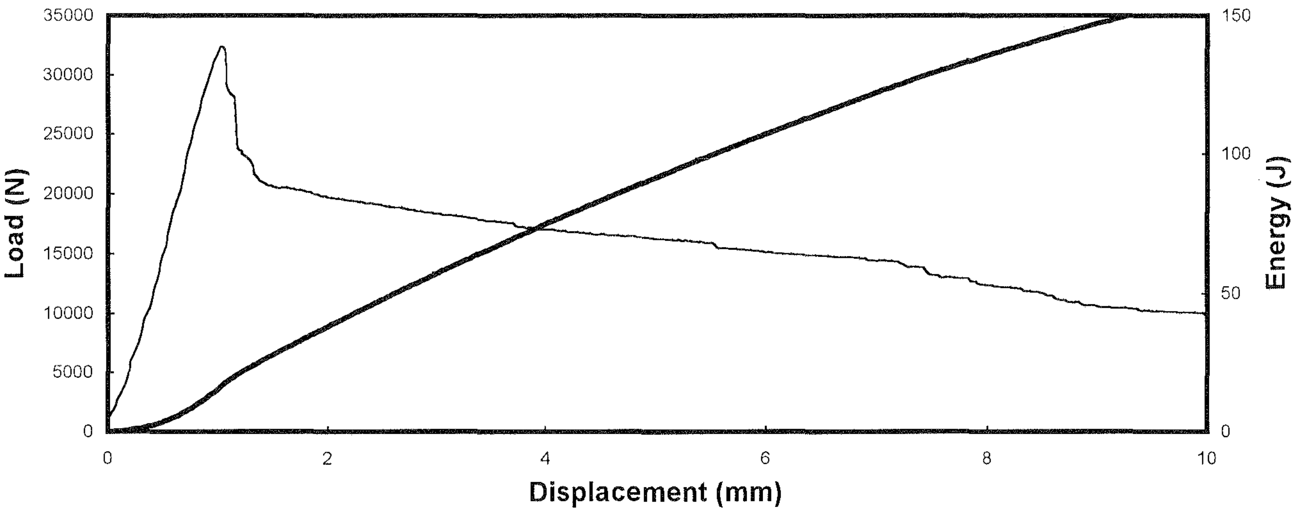
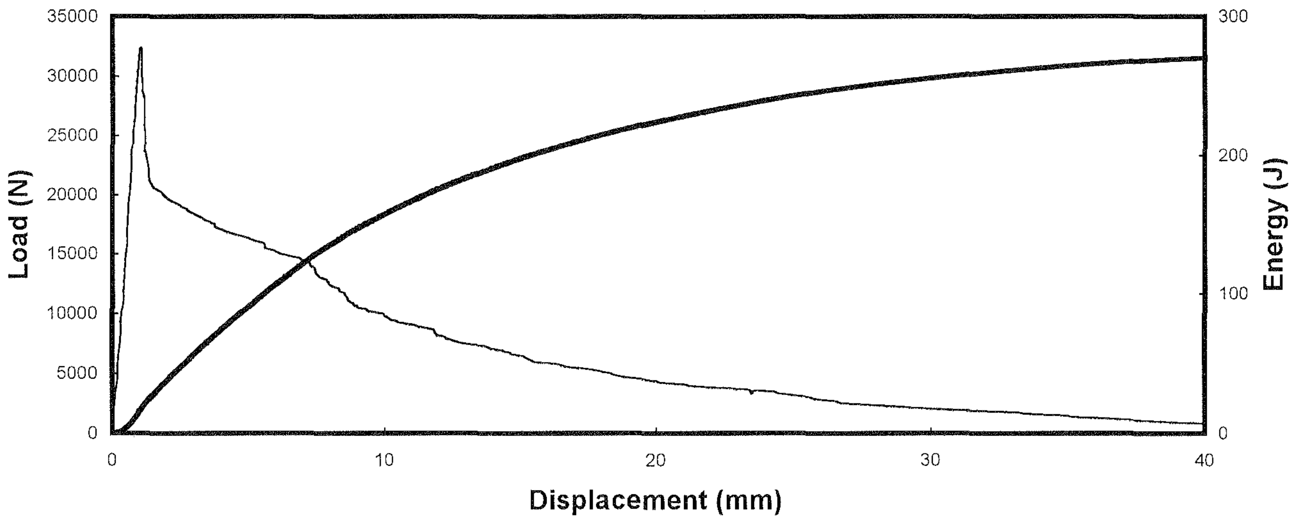
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V1-D12

Set: V1 Panel Set **Age:** 56 days **Date:** 1/15/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
800	11	78
804	14	78
803	18	78
	12	78
	13	79
mean: 802.3	7	75
	13	77
	19	78
	16	79
	14	76
	x: 13.7	77.6
	cov: 25.3	1.6

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

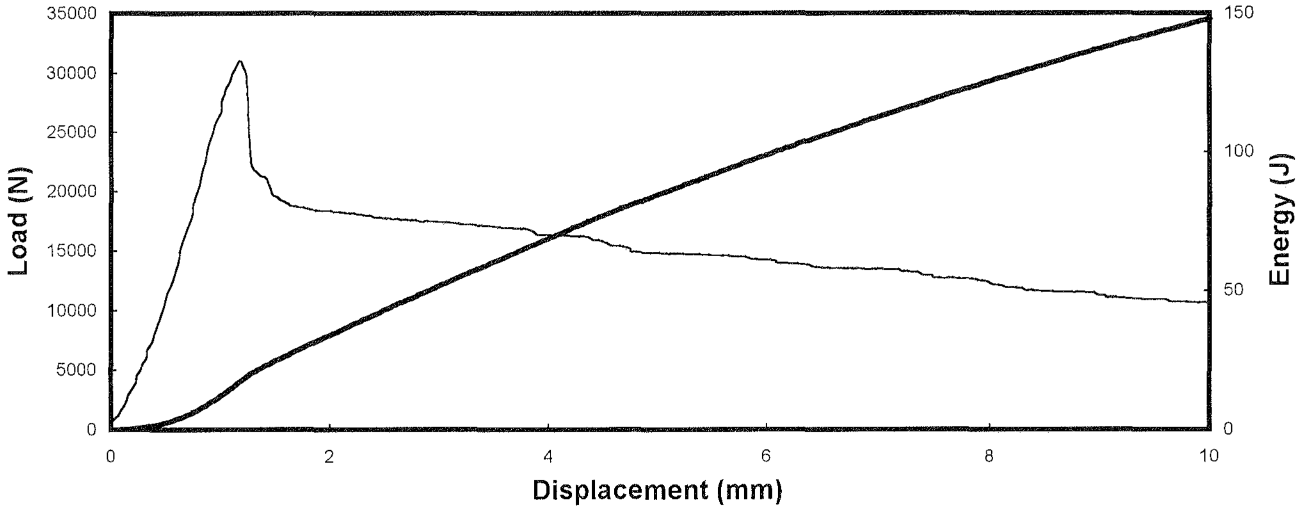
Parameter	Raw Results	Corrected
Peak Load (N)	**32394** N	**30172** N
Energy at 5 mm	**91** J	**85** J
Energy at 10 mm	**157** J	**147** J
Energy at 20 mm	**224** J	**210** J
Energy at 40 mm	**270** J	**256** J

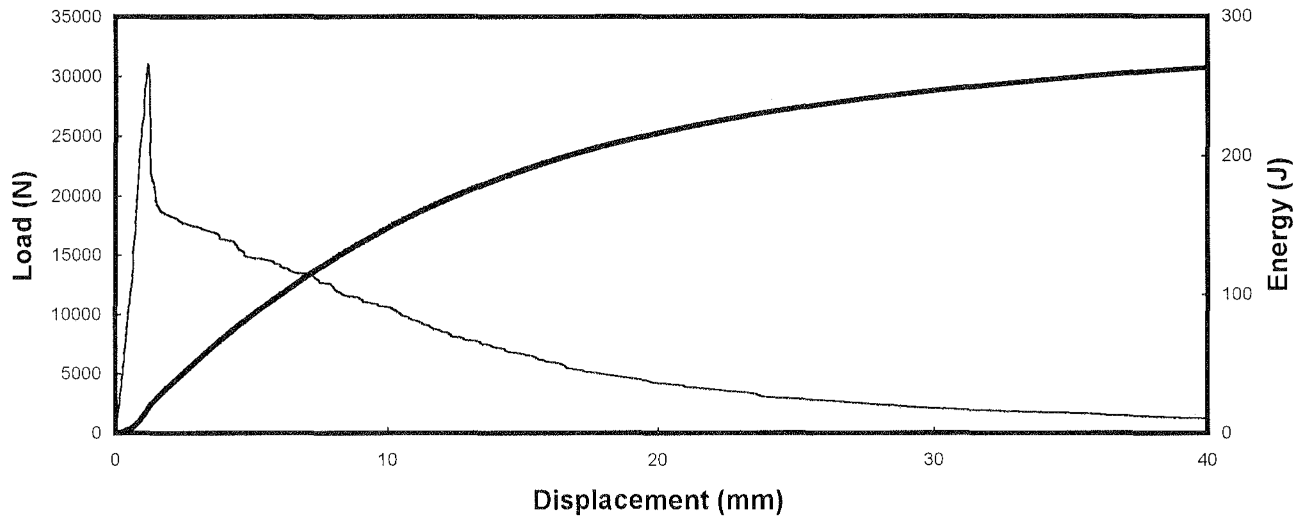
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V1-D13

Set: V1 Panel Set **Age:** 56 days **Date:** 1/15/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
800	12	76
802	18	76
804	13	75
	17	75
	12	75
mean: 802.0	12	77
	13	78
	25	78
	16	75
	10	76
x:	14.8	76.1
cov:	29.7	1.6

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**30990** N	**30026** N
Energy at 5 mm	**84** J	**81** J
Energy at 10 mm	**148** J	**143** J
Energy at 20 mm	**216** J	**210** J
Energy at 40 mm	**263** J	**257** J

Performance corrections carried out according to Bernard and Pircher (2000)

2.2.2. Concrete Set 2

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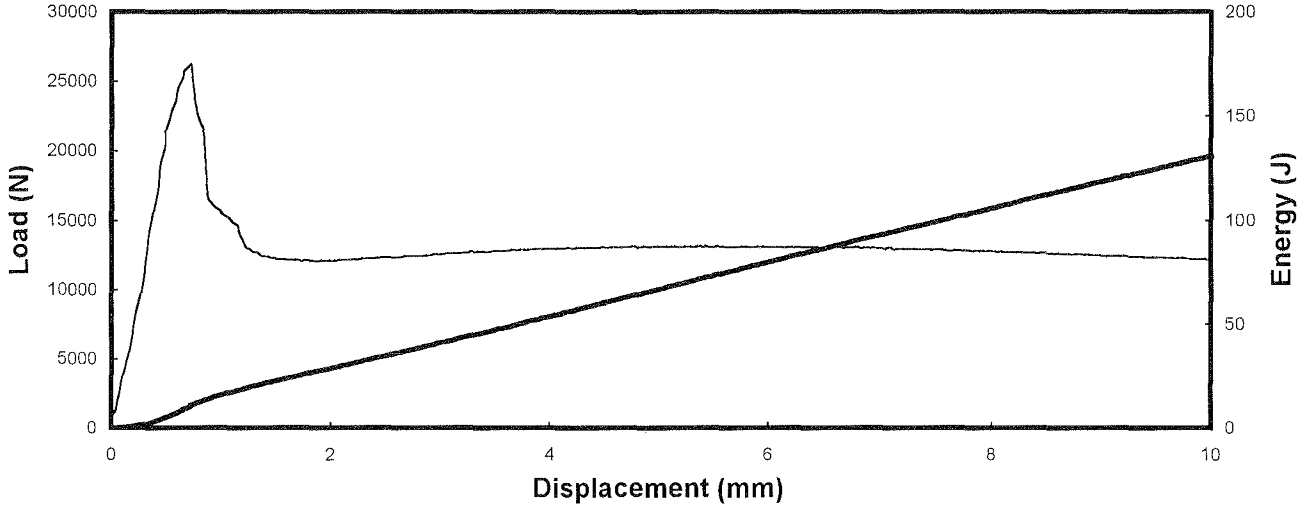
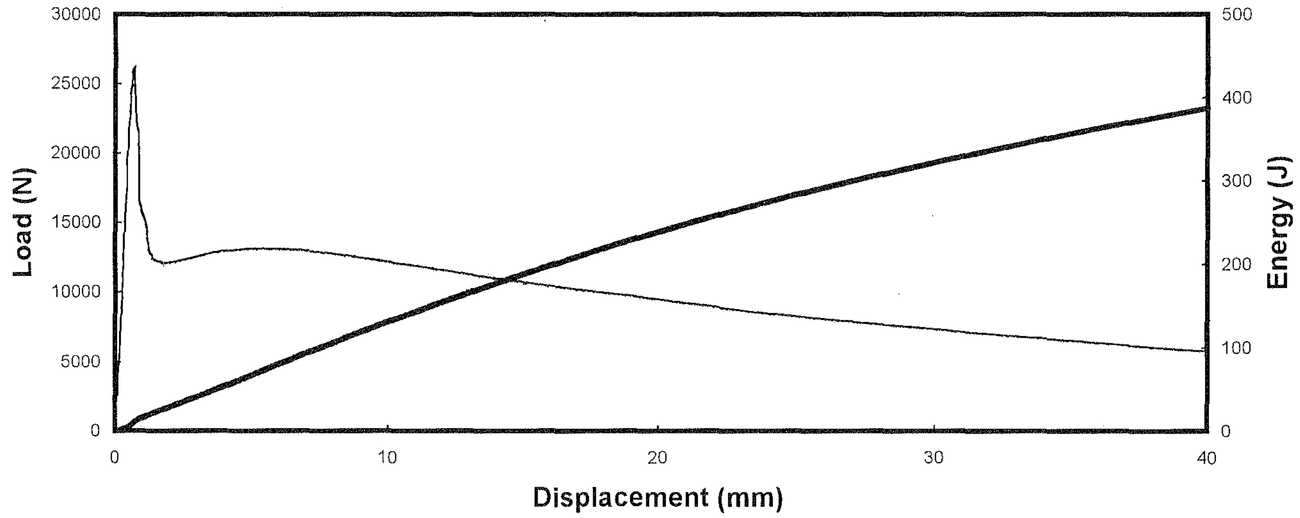
Round Determinate Panel Test Result **Specimen ID:** V2-D01

Set: V2 Panel Set **Age:** 107 day **Date:** 1/5/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
800	44	74
800	60	74
797	53	77
	64	77
	56	77
mean: 799.0	67	77
	67	72
	62	74
	75	74
	67	72
	x: 61.5	74.8
	cov: 14.2	2.7

Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**26296** N	**26470** N
Energy at 5 mm	**66** J	**67** J
Energy at 10 mm	**130** J	**131** J
Energy at 20 mm	**238** J	**240** J
Energy at 40 mm	**387** J	**389** J

Performance corrections carried out according to Bernard and Pircher (2000)

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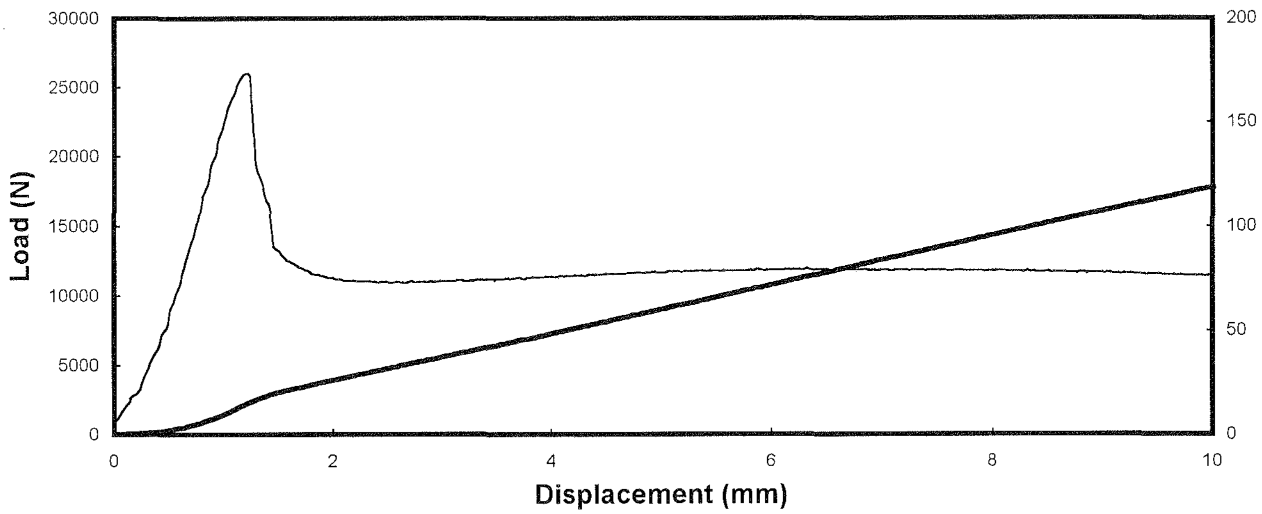
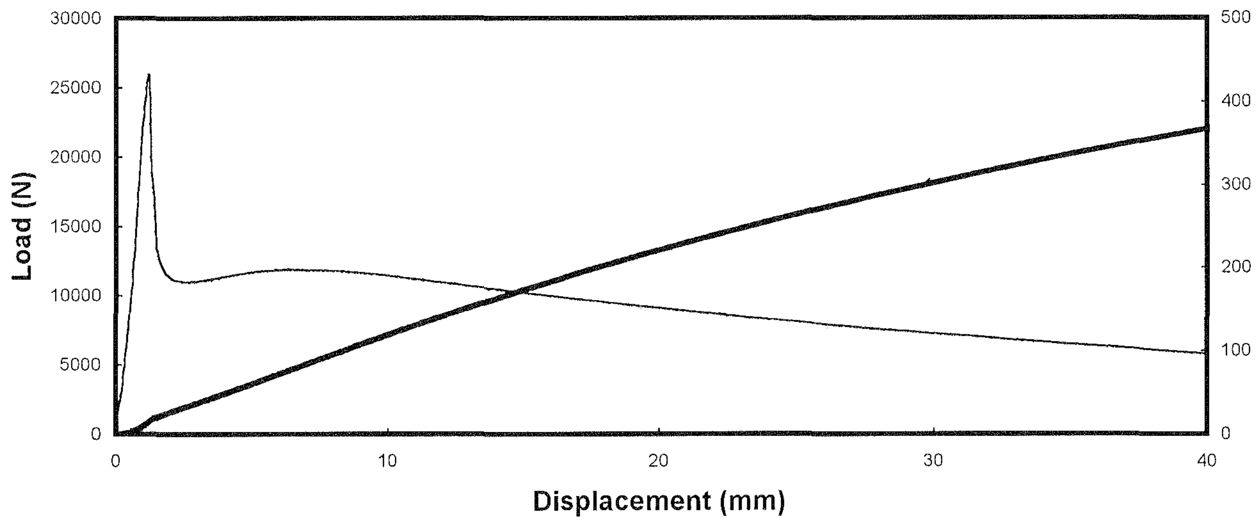
Round Determinate Panel Test Result **Specimen ID:** V2-D02

Set: V2 Panel Set **Age:** 107 day **Date:** 1/5/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
805	67	77
797	71	77
800	75	77
	59	74
	44	77
mean: 800.7	49	78
	53	78
	60	78
	62	78
	47	78
	x: 58.7	77.2
	cov: 17.8	1.6

Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**26020** N	**24538** N
Energy at 5 mm	**59** J	**56** J
Energy at 10 mm	**118** J	**112** J
Energy at 20 mm	**221** J	**210** J
Energy at 40 mm	**367** J	**351** J

Performance corrections carried out according to Bernard and Pircher (2000)

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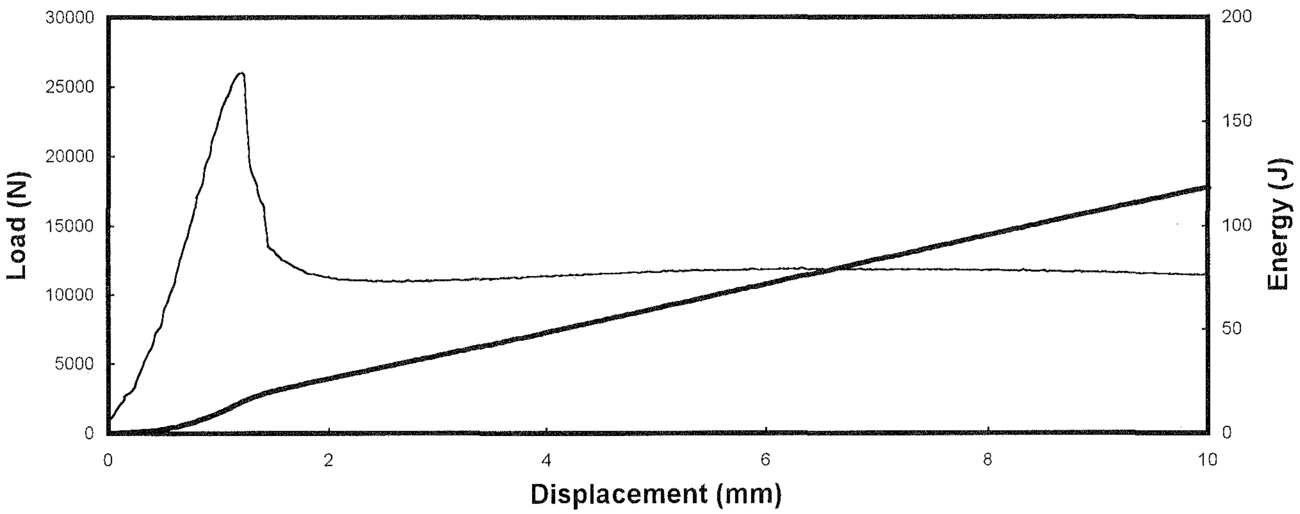
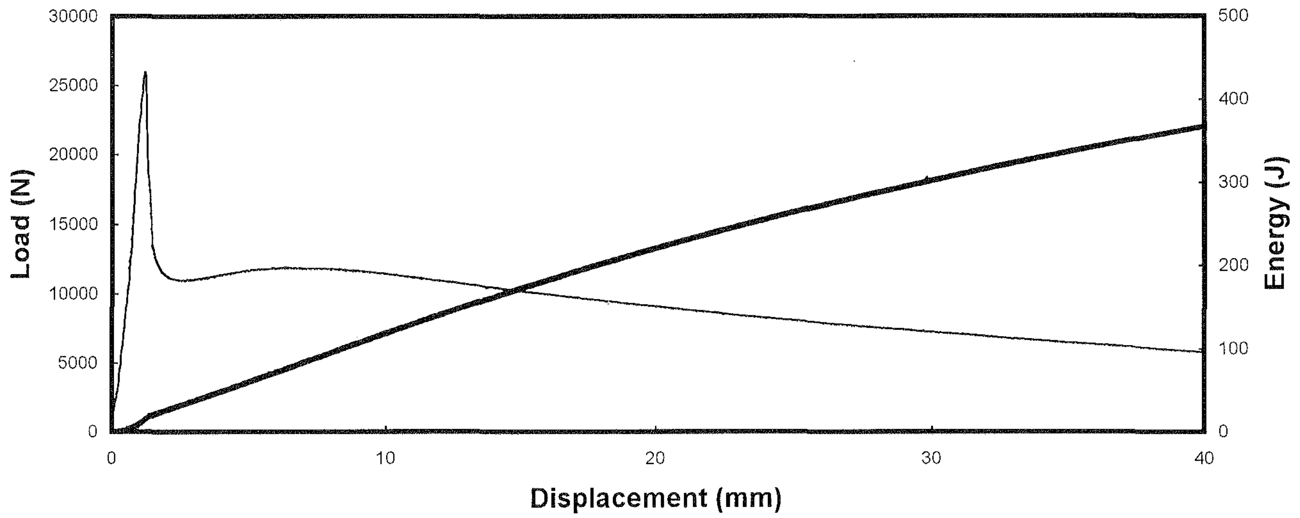
Round Determinate Panel Test Result **Specimen ID:** V2-D03

Set: V2 Panel Set **Age:** 107 day **Date:** 1/5/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
805	67	77
797	71	77
800	75	77
	59	74
	44	77
mean: 800.7	49	78
Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.	53	78
	60	78
	62	78
	47	78
	x: 58.7	77.2
	cov: 17.8	1.6

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**26020** N	**24538** N
Energy at 5 mm	**59** J	**56** J
Energy at 10 mm	**118** J	**112** J
Energy at 20 mm	**221** J	**210** J
Energy at 40 mm	**367** J	**351** J

Performance corrections carried out according to Bernard and Pircher (2000)

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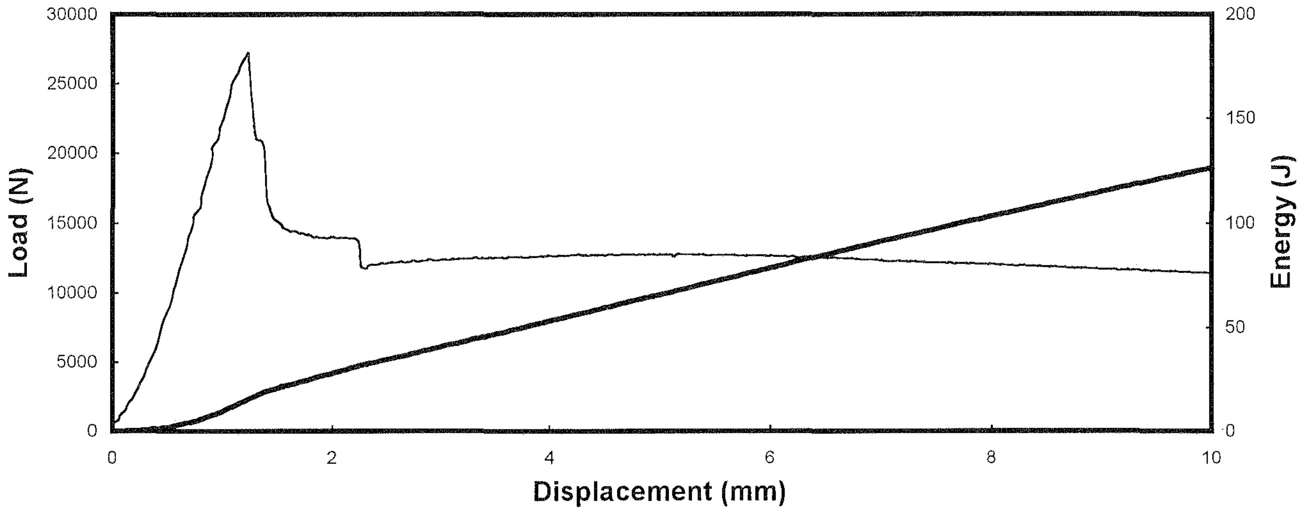
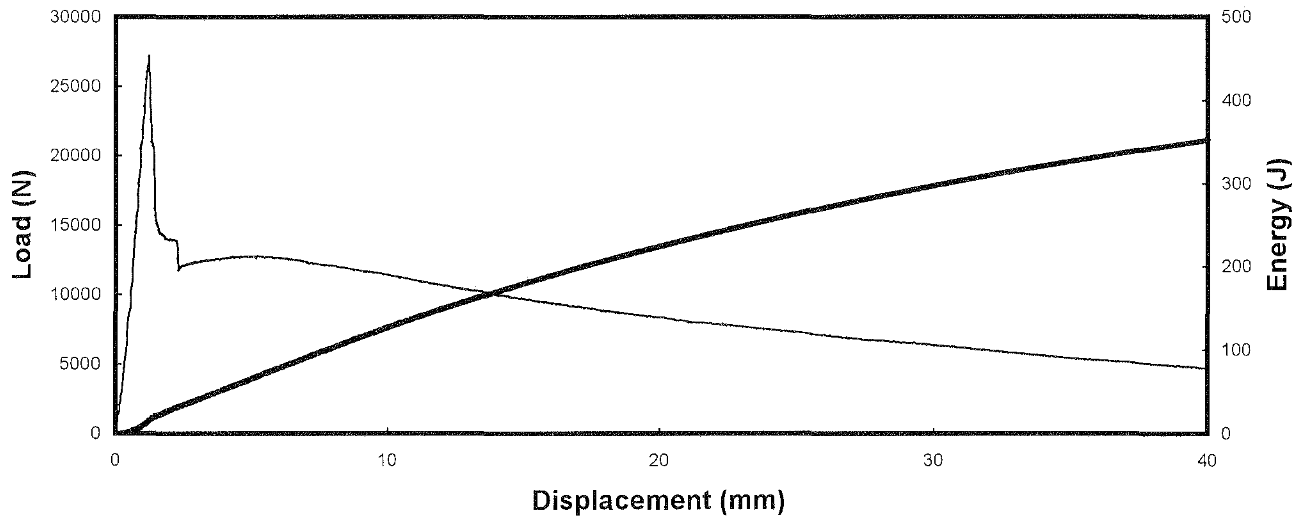
Round Determinate Panel Test Result **Specimen ID:** V2-D04

Set: V2 Panel Set **Age:** 107 day **Date:** 1/5/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
805	81	77
803	55	78
802	44	78
	43	76
	39	76
mean: 803.3	45	77
	46	75
	60	77
	45	75
	57	76
	x: 51.5	76.5
	cov: 24.1	1.4

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**27278** N	**26110** N
Energy at 5 mm	**65** J	**63** J
Energy at 10 mm	**126** J	**121** J
Energy at 20 mm	**224** J	**215** J
Energy at 40 mm	**352** J	**340** J

Performance corrections carried out according to Bernard and Pircher (2000)

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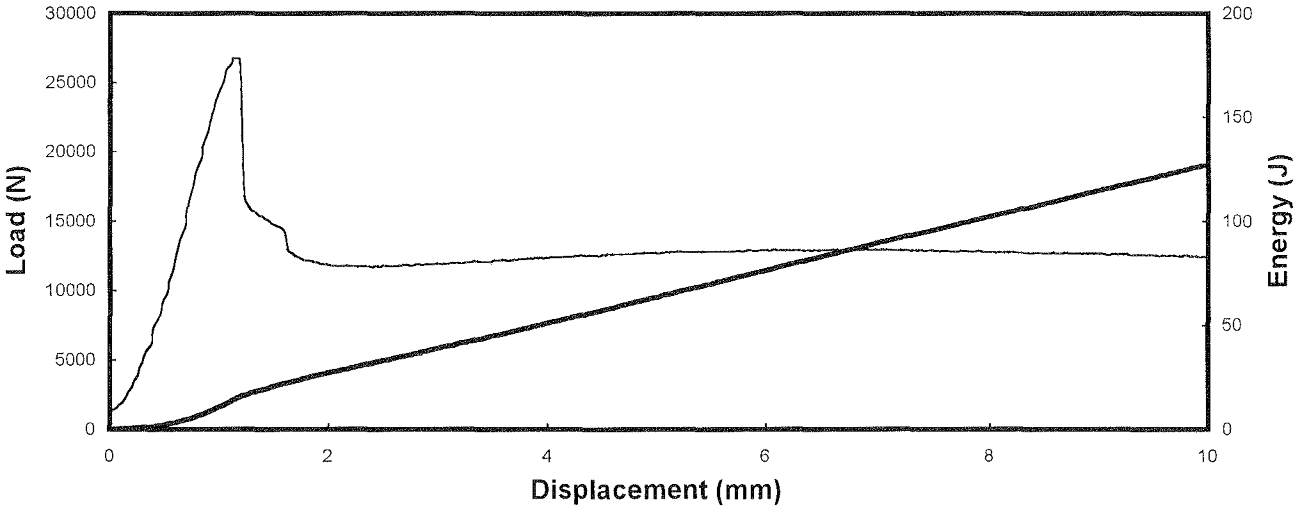
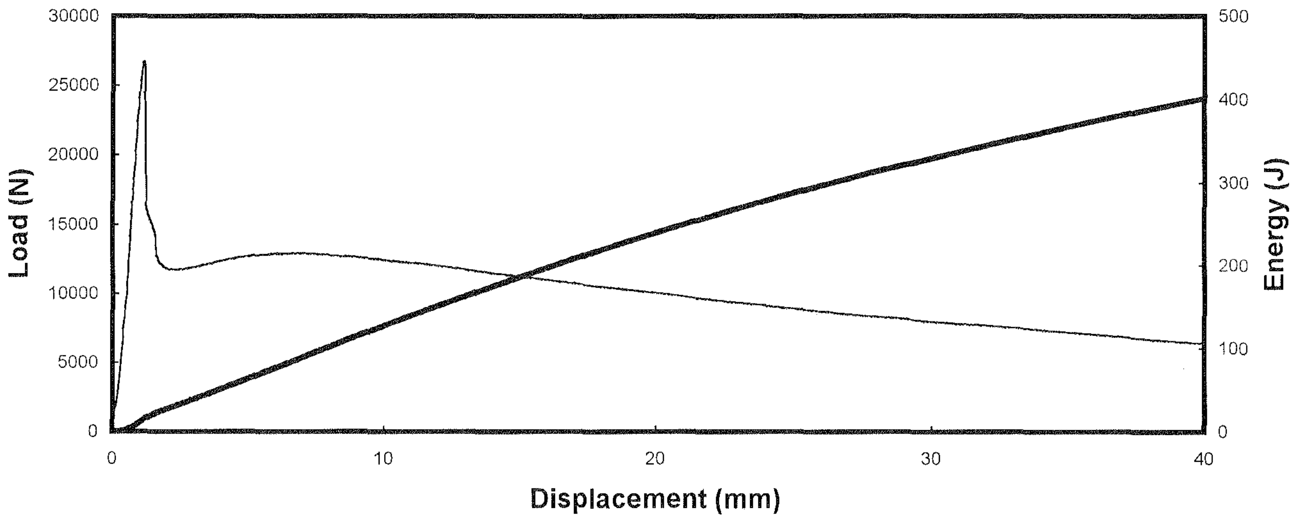
Round Determinate Panel Test Result **Specimen ID:** V2-D05

Set: V2 Panel Set **Age:** 107 day **Date:** 1/5/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
808	91	75
803	58	76
808	74	77
	48	75
	51	76
mean: 806.3	54	76
	62	75
	52	77
	52	75
	46	76
	x: 58.8	75.8
	cov: 23.6	1.0

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**26753** N	**25985** N
Energy at 5 mm	**63** J	**62** J
Energy at 10 mm	**127** J	**124** J
Energy at 20 mm	**239** J	**233** J
Energy at 40 mm	**401** J	**391** J

Performance corrections carried out according to Bernard and Pircher (2000)

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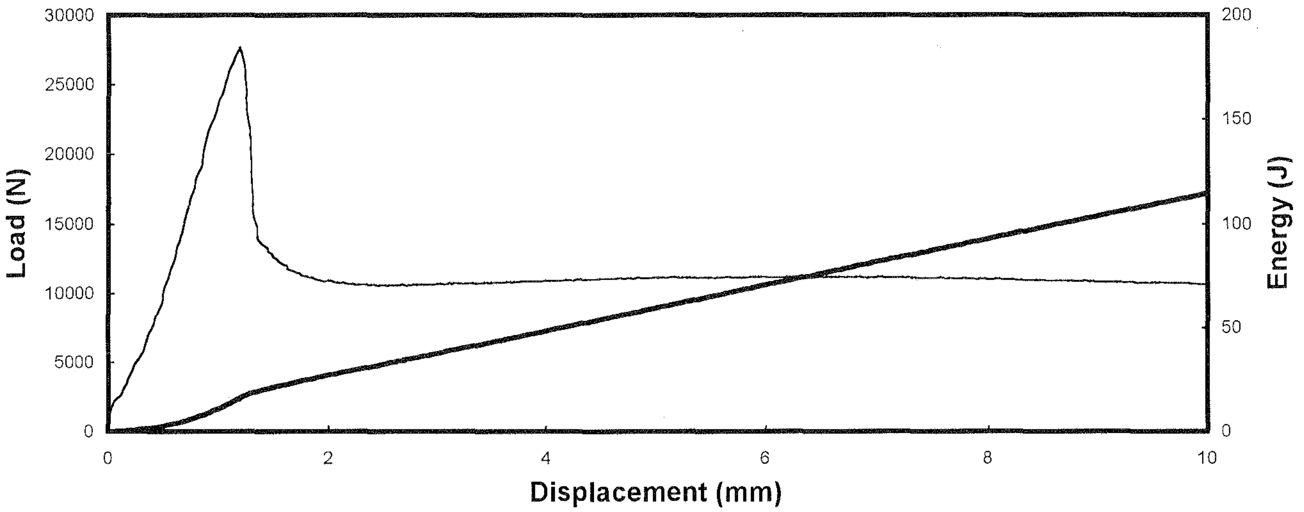
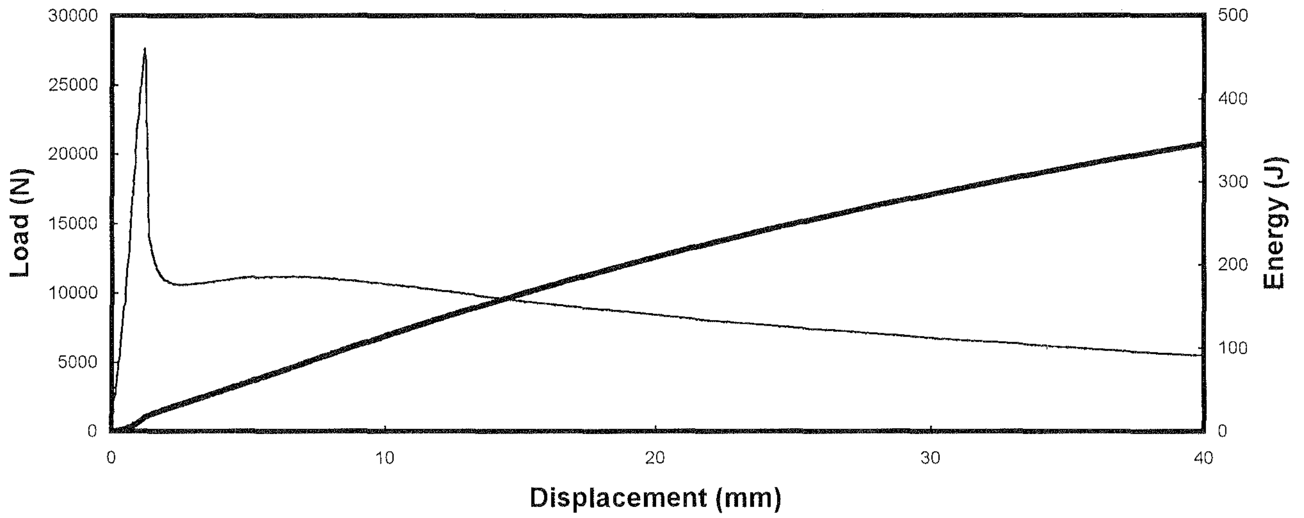
Round Determinate Panel Test Result **Specimen ID:** V2-D06

Set: V2 Panel Set **Age:** 107 day **Date:** 1/5/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
803	58	75
806	52	74
803	51	81
	52	78
	45	79
mean: 804.0	61	76
	48	76
	53	73
	54	76
	46	82
	x: 52	77.0
	cov: 9.6	3.8

Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	27674 N	26125 N
Energy at 5 mm	59 J	56 J
Energy at 10 mm	114 J	108 J
Energy at 20 mm	209 J	199 J
Energy at 40 mm	345 J	330 J

Performance corrections carried out according to Bernard and Pircher (2000)

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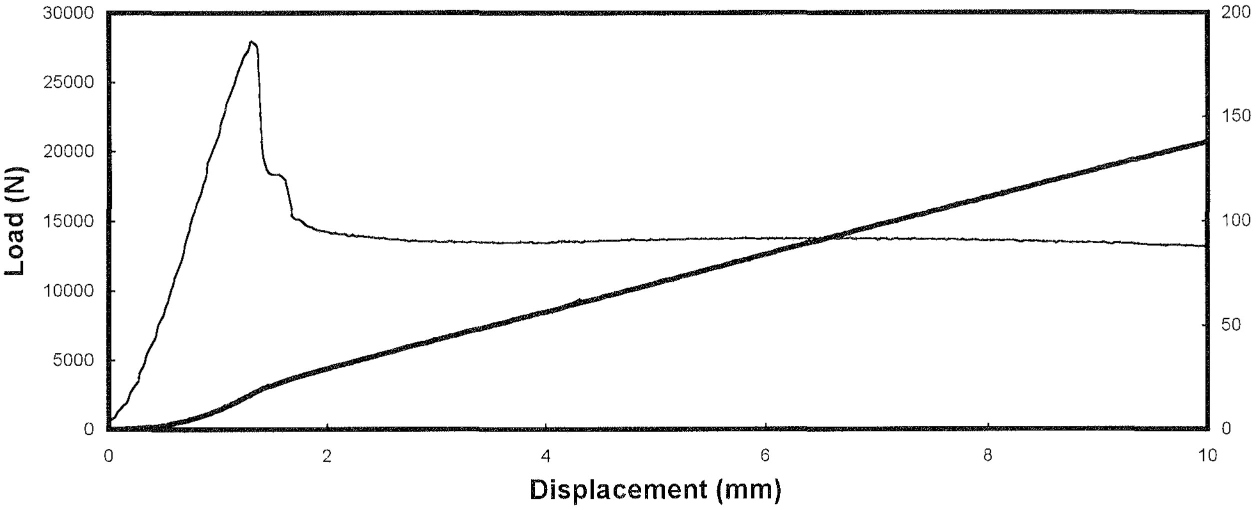
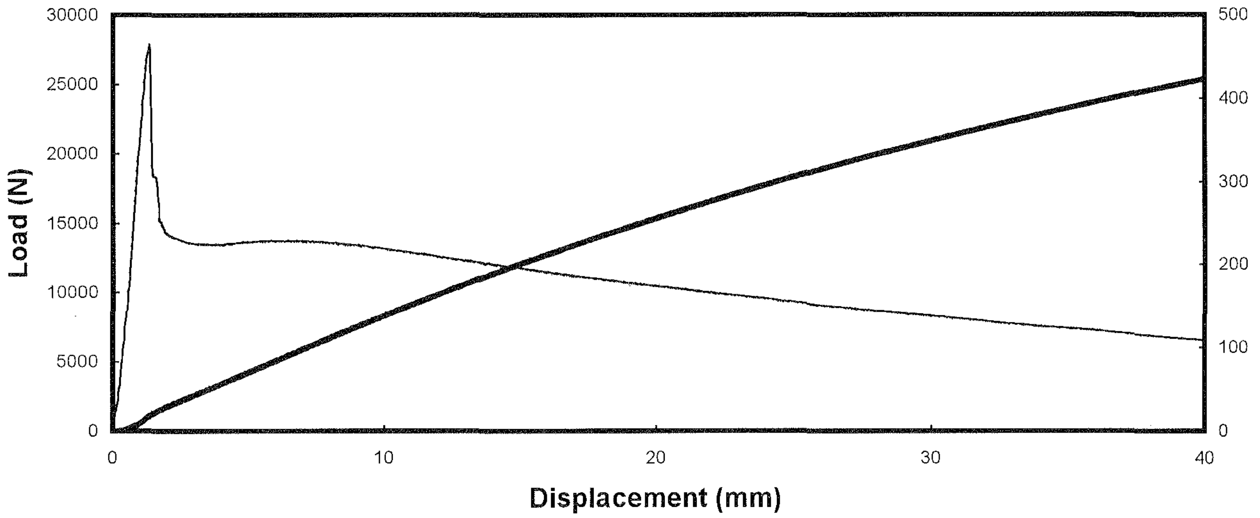
Round Determinate Panel Test Result | **Specimen ID:** V2-D07

Set: V2 Panel Set | **Age:** 107 day | **Date:** 1/5/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
805	45	74
803	62	76
804	53	76
	65	78
	58	76
mean: 804.0	55	77
	56	77
	51	76
	51	78
	49	75
x:	54.5	76.3
cov:	11.1	1.6

Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**27941** N	**26863** N
Energy at 5 mm	**70** J	**67** J
Energy at 10 mm	**138** J	**133** J
Energy at 20 mm	**255** J	**247** J
Energy at 40 mm	**423** J	**410** J

Performance corrections carried out according to Bernard and Pircher (2000)

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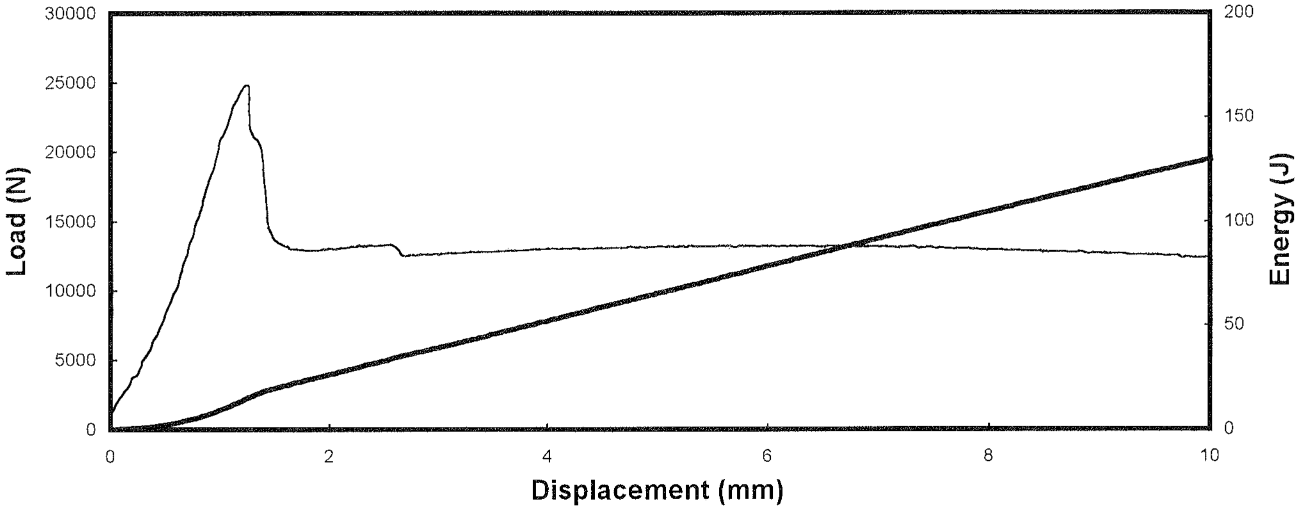
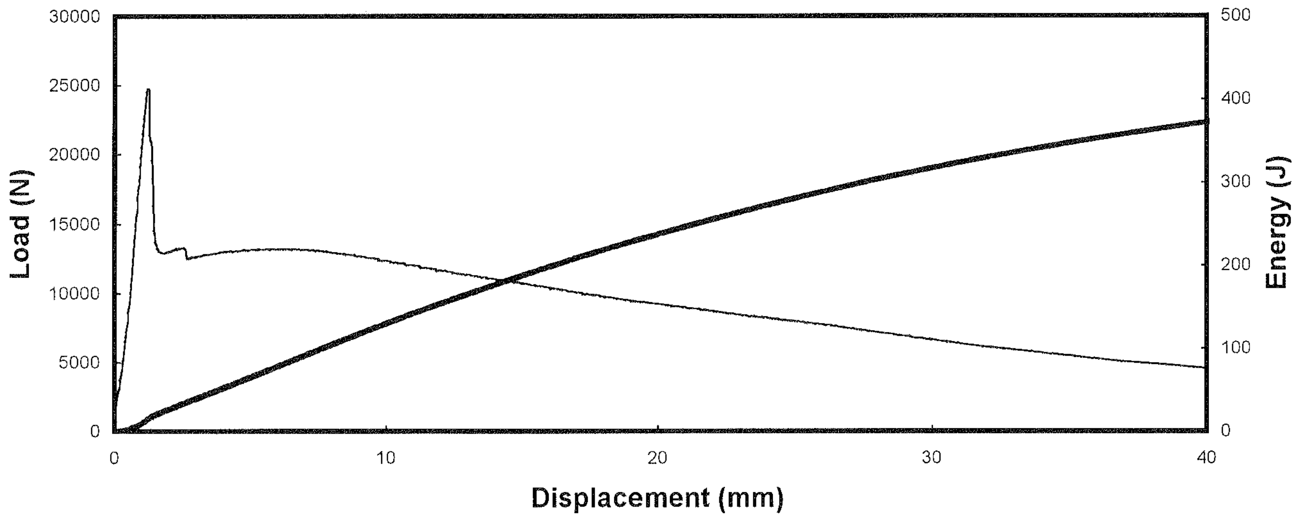
Round Determinate Panel Test Result **Specimen ID:** V2-D08

Set: V2 Panel Set **Age:** 107 day **Date:** 1/5/01





Specimen Dimensions

	Diameter (mm)	Fibres	Thickness (mm)
	803	42	74
	805	51	74
	804	48	75
		55	74
		38	74
mean:	804.0	49	75
		47	77
		52	77
		48	76
		42	77
x:		47.2	75.3
cov:		11.0	1.8

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**24797** N	**24478** N
Energy at 5 mm	**65** J	**64** J
Energy at 10 mm	**129** J	**128** J
Energy at 20 mm	**237** J	**234** J
Energy at 40 mm	**372** J	**368** J

Performance corrections carried out according to Bernard and Pircher (2000)

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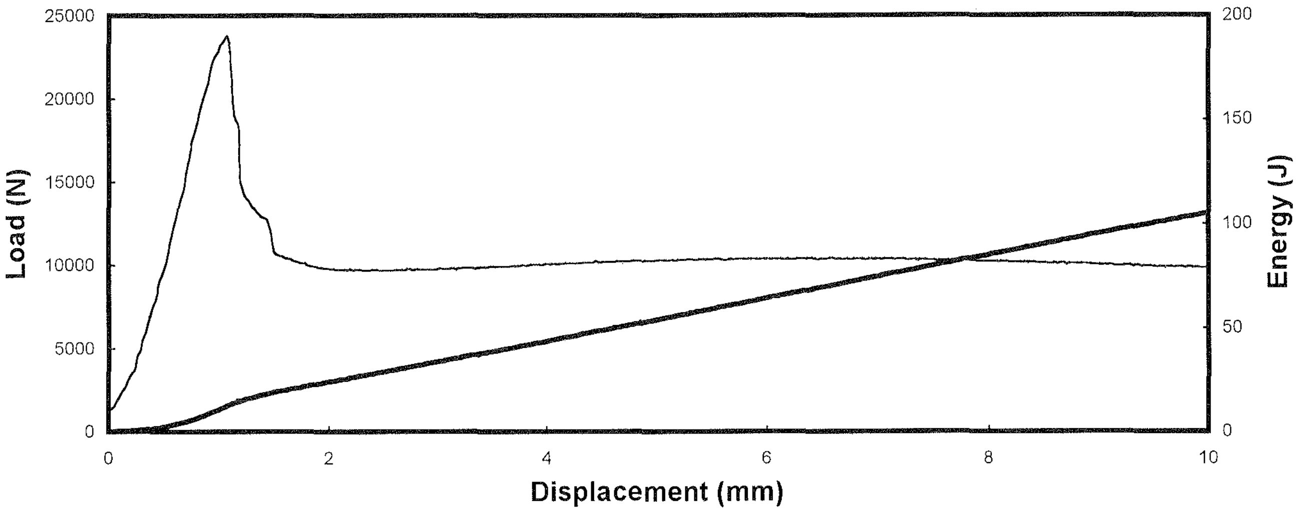
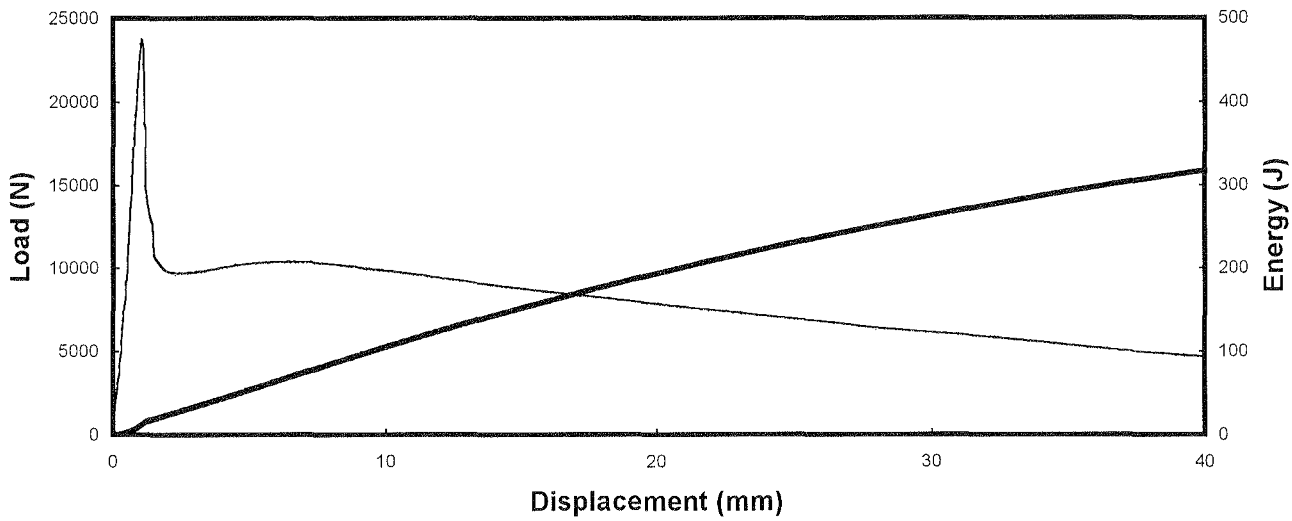
Round Determinate Panel Test Result **Specimen ID:** V2-D09

Set: V2 Panel Set **Age:** 107 day **Date:** 1/5/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
798	56	74
795	57	76
800	58	76
	43	76
	40	77
mean: 797.7	43	74
	65	76
	44	76
	43	77
	63	74
	x: 51.2	75.6
	cov: 18.5	1.6

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with two primary radial cracks.
Third crack was smaller than others.

Parameter	Raw Results	Corrected
Peak Load (N)	**23755** N	**23448** N
Energy at 5 mm	**54** J	**53** J
Energy at 10 mm	**105** J	**104** J
Energy at 20 mm	**193** J	**191** J
Energy at 40 mm	**317** J	**314** J

Performance corrections carried out according to Bernard and Pircher (2000)

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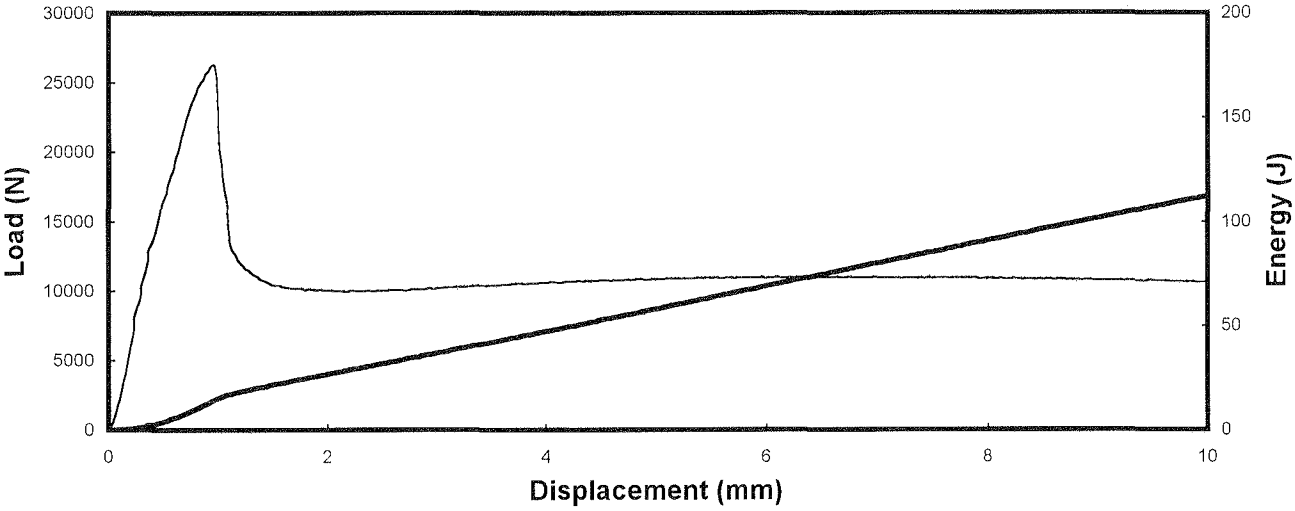
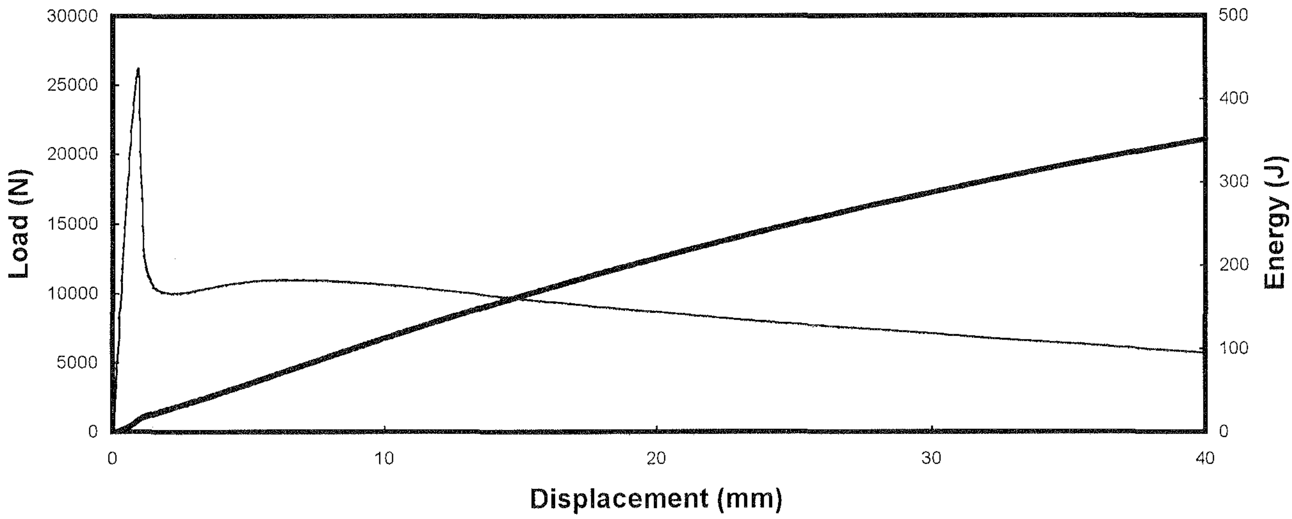
Round Determinate Panel Test Result **Specimen ID:** V2-D10

Set: V2 Panel Set **Age:** 107 day **Date:** 1/5/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
803	52	73
795	54	74
801	42	73
	49	76
	56	75
mean: 799.7	58	76
	50	75
	50	76
	60	74
	50	73
	x: 52.1	74.5
	cov: 9.9	1.7

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**26262** N	**26626** N
Energy at 5 mm	**58** J	**59** J
Energy at 10 mm	**112** J	**113** J
Energy at 20 mm	**208** J	**211** J
Energy at 40 mm	**351** J	**354** J

Performance corrections carried out according to Bernard and Pircher (2000)

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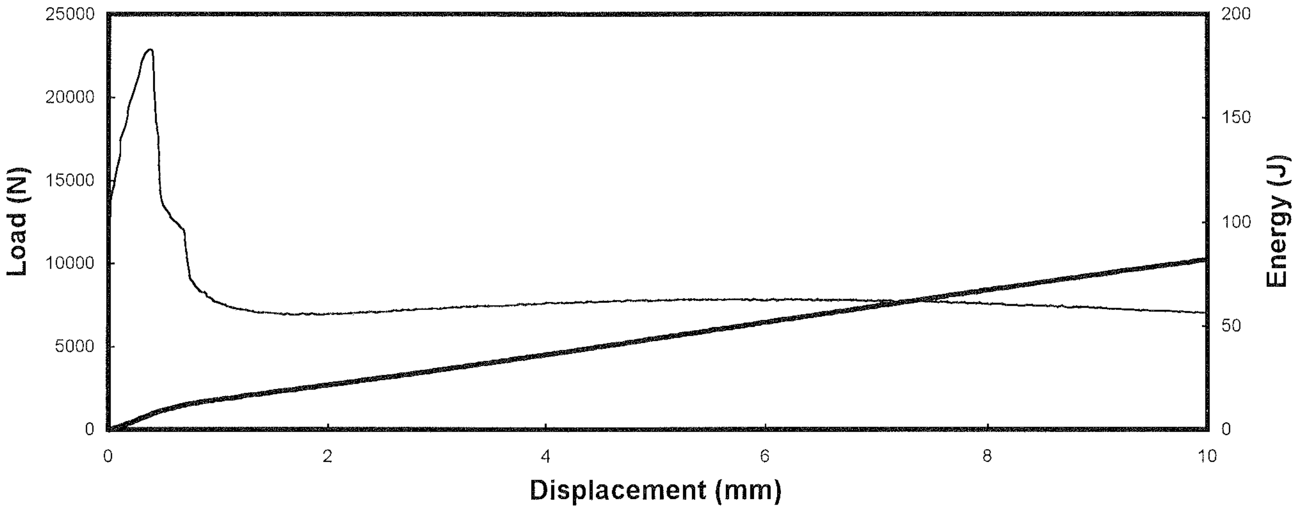
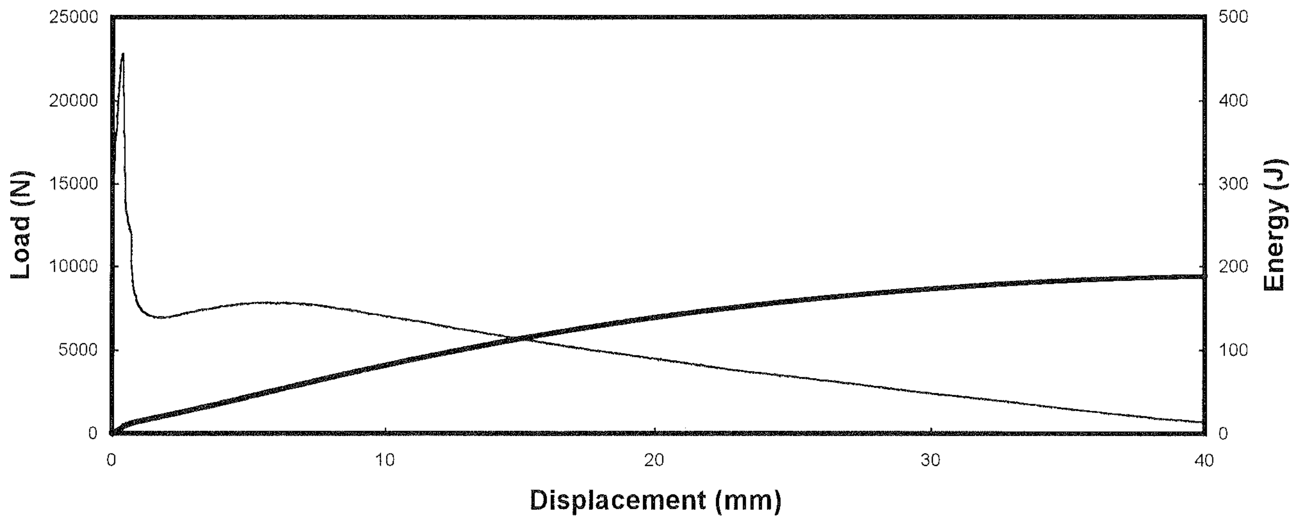
Round Determinate Panel Test Result **Specimen ID:** V2-D11

Set: V2 Panel Set **Age:** 107 day **Date:** 1/5/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
795	47	77
803	62	77
810	52	77
	43	76
	51	77
mean: 802.7	56	77
	64	77
	53	76
	49	77
	43	77
	x: 52	76.8
	cov: 13.7	0.5

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**22887** N	**21754** N
Energy at 5 mm	**44** J	**42** J
Energy at 10 mm	**82** J	**78** J
Energy at 20 mm	**139** J	**133** J
Energy at 40 mm	**188** J	**181** J

Performance corrections carried out according to Bernard and Pircher (2000)

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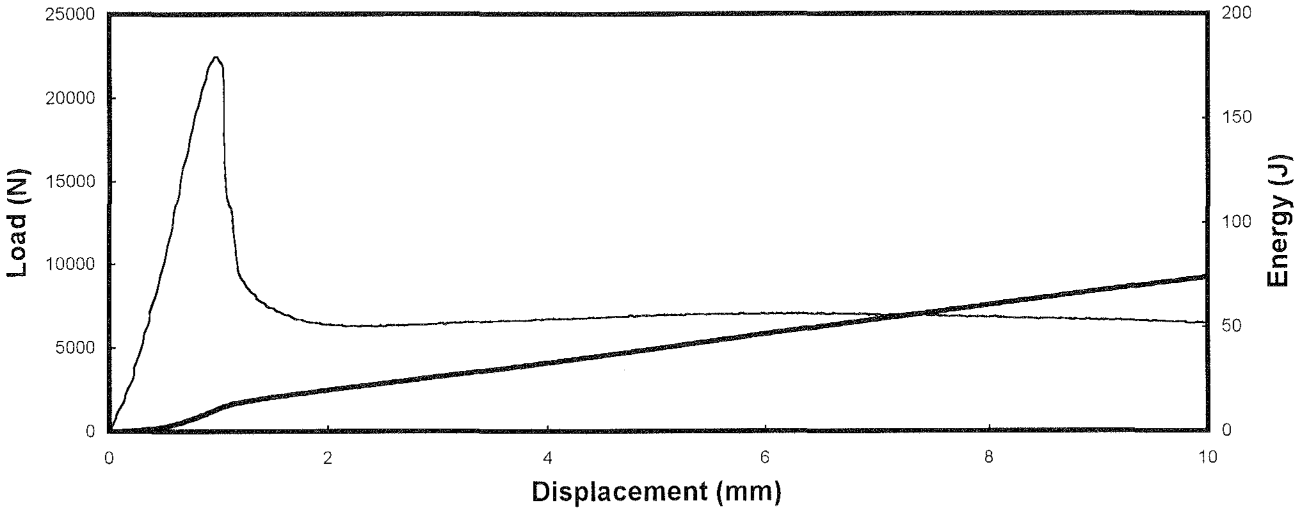
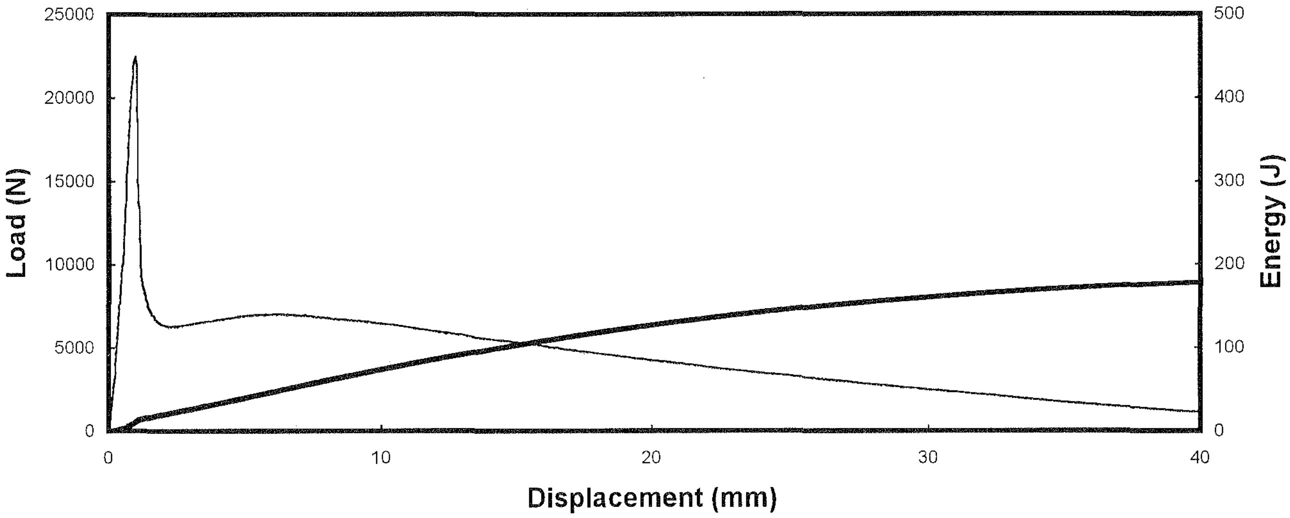
Round Determinate Panel Test Result | **Specimen ID:** V2-D12

Set: V2 Panel Set | **Age:** 107 day **Date:** 1/5/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
803	60	79
806	45	80
804	51	79
	55	78
	39	78
mean: 804.3	48	76
	53	76
	41	80
	45	78
	43	80
	x: 48	78.4
	cov: 13.9	1.9

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**22515** N	**20493** N
Energy at 5 mm	**39** J	**36** J
Energy at 10 mm	**74** J	**67** J
Energy at 20 mm	**127** J	**117** J
Energy at 40 mm	**178** J	**166** J

Performance corrections carried out according to Bernard and Pircher (2000)

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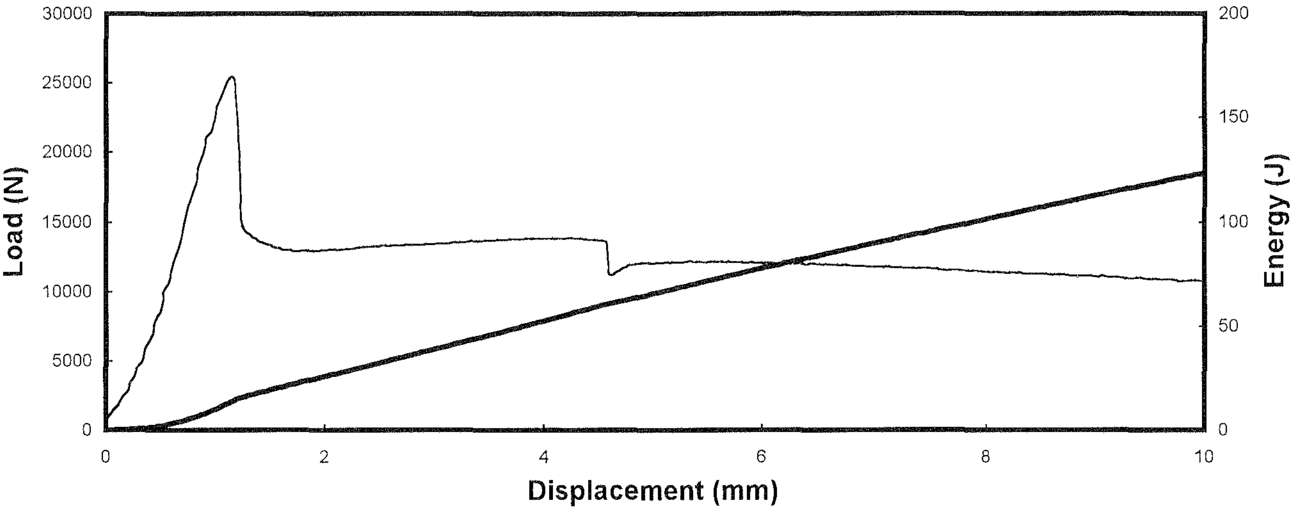
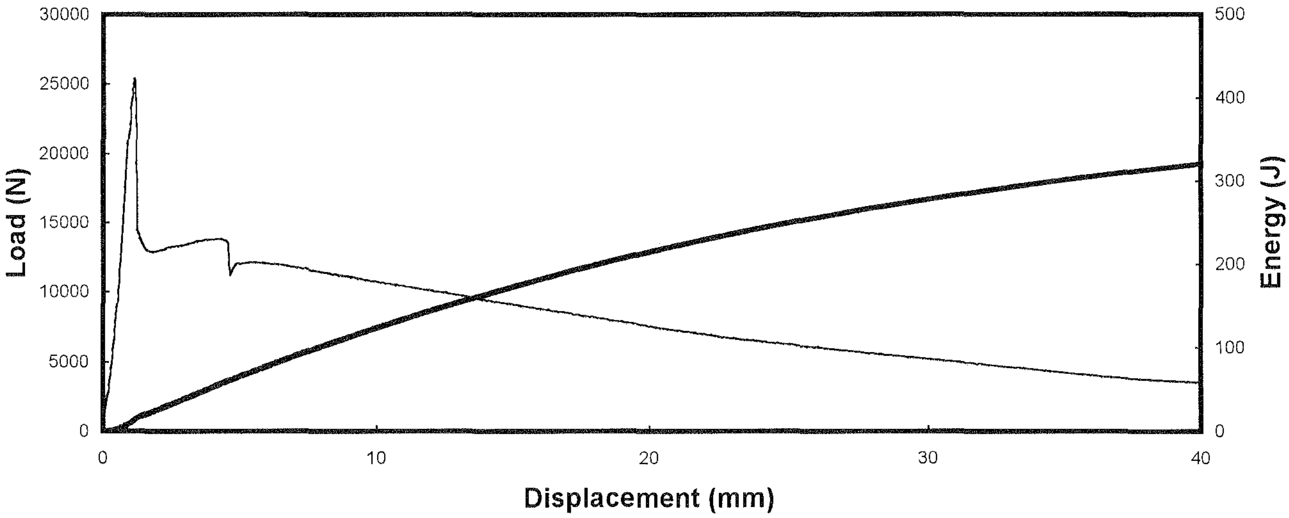
Round Determinate Panel Test Result **Specimen ID:** V2-D13

Set: V2 Panel Set **Age:** 110 day **Date:** 1/8/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
808	39	75
805	43	79
809	37	77
	38	75
	26	79
mean: 807.3	39	78
	45	76
	39	74
	54	77
	30	79
x:	39	76.9
cov:	19.7	2.4

Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**25461** N	**23998** N
Energy at 5 mm	**65** J	**62** J
Energy at 10 mm	**123** J	**117** J
Energy at 20 mm	**215** J	**203** J
Energy at 40 mm	**320** J	**305** J

Performance corrections carried out according to Bernard and Pircher (2000)

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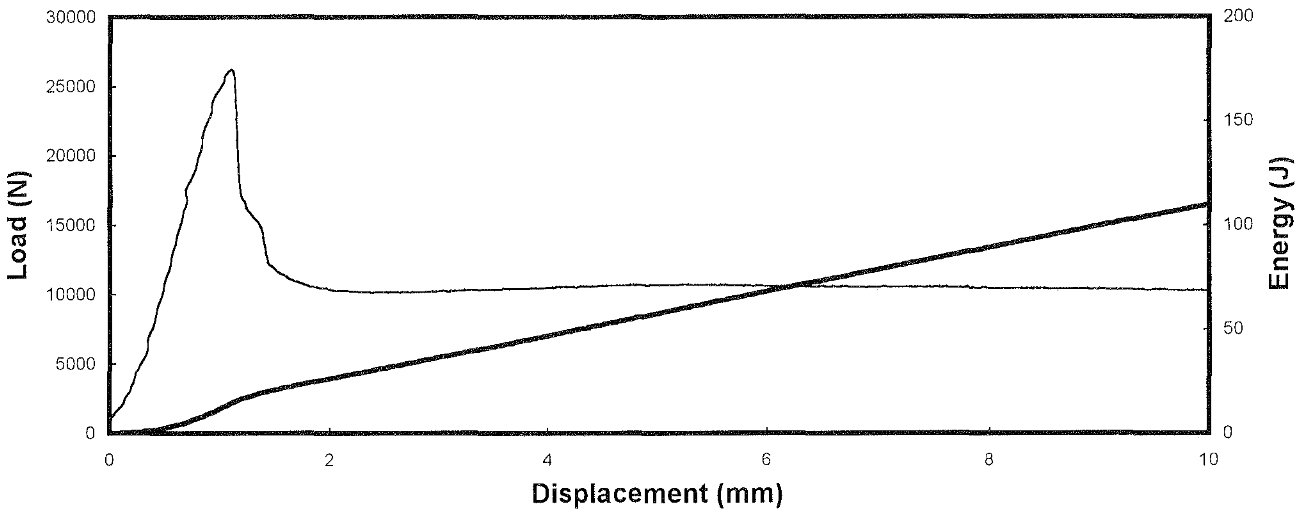
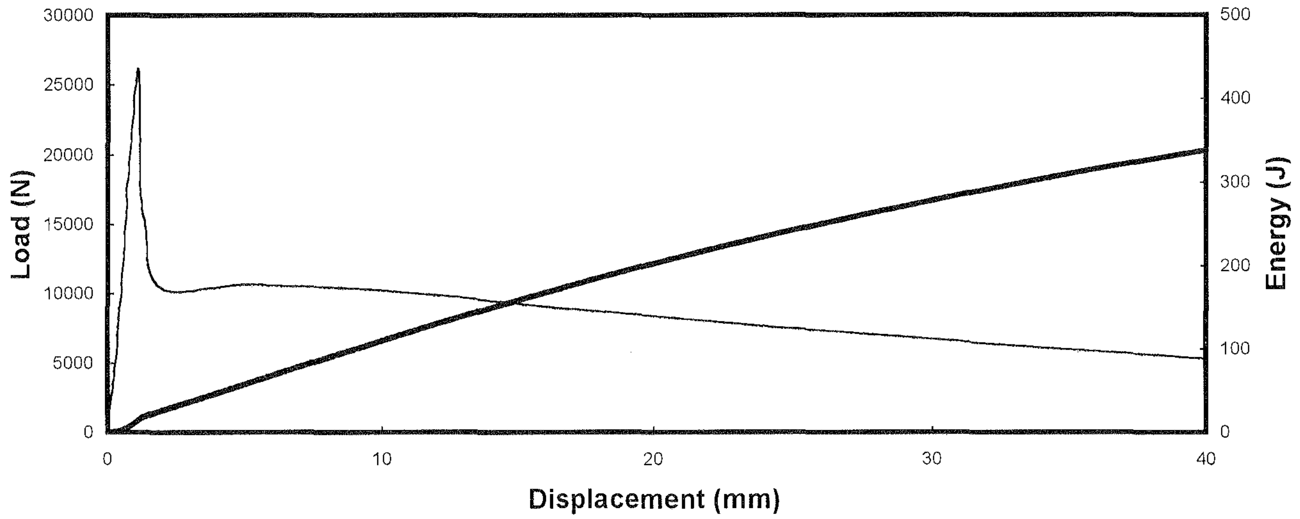
Round Determinate Panel Test Result **Specimen ID:** V2-D14

Set: V2 Panel Set **Age:** 110 day **Date:** 1/8/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
802	36	75
801	39	76
799	31	74
	33	75
	40	73
mean: 800.7	34	72
	35	79
	38	76
	32	77
	35	76
	x: 35.3	75.3
	cov: 8.5	2.7

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**26176** N	**25946** N
Energy at 5 mm	**57** J	**57** J
Energy at 10 mm	**109** J	**108** J
Energy at 20 mm	**203** J	**201** J
Energy at 40 mm	**338** J	**335** J

Performance corrections carried out according to Bernard and Pircher (2000)

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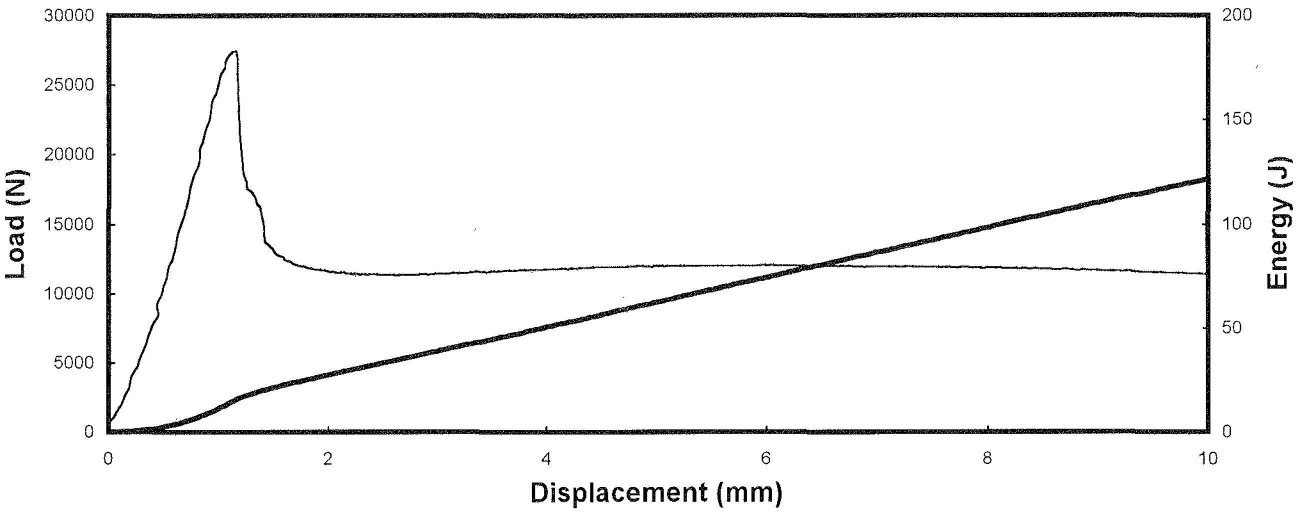
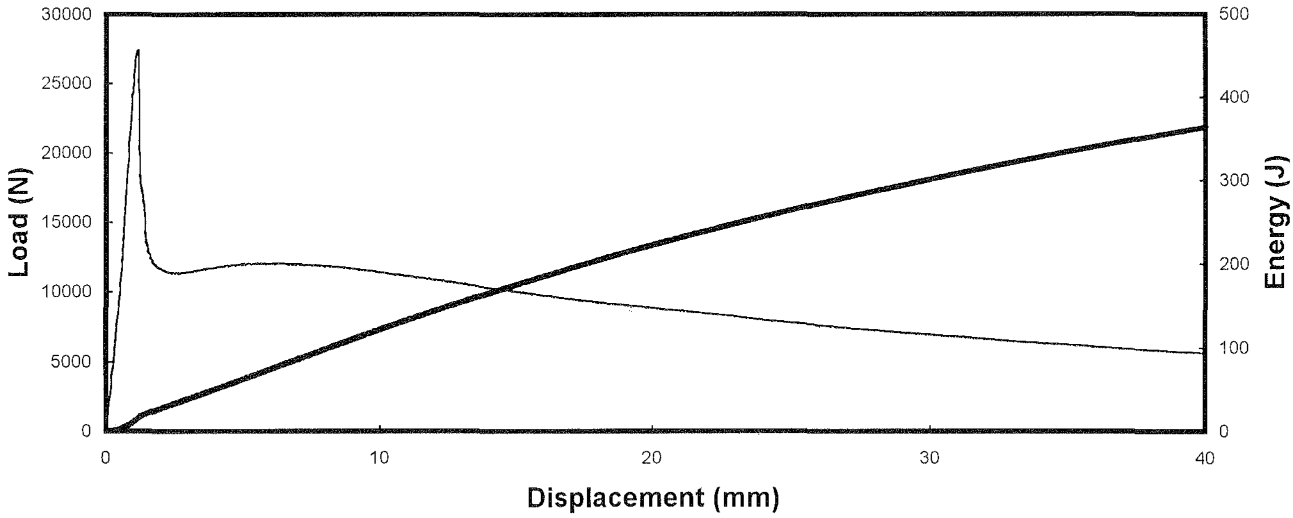
Round Determinate Panel Test Result **Specimen ID:** V2-D15

Set: V2 Panel Set **Age:** 110 day **Date:** 1/8/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
803	36	74
808	41	81
801	35	77
	40	78
	43	77
mean: 804.0	37	81
	42	75
	36	76
	45	78
	38	78
	x: 39.3	77.5
	cov: 8.7	2.9

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**27476** N	**25604** N
Energy at 5 mm	**62** J	**58** J
Energy at 10 mm	**121** J	**114** J
Energy at 20 mm	**222** J	**209** J
Energy at 40 mm	**363** J	**344** J

Performance corrections carried out according to Bernard and Pircher (2000)

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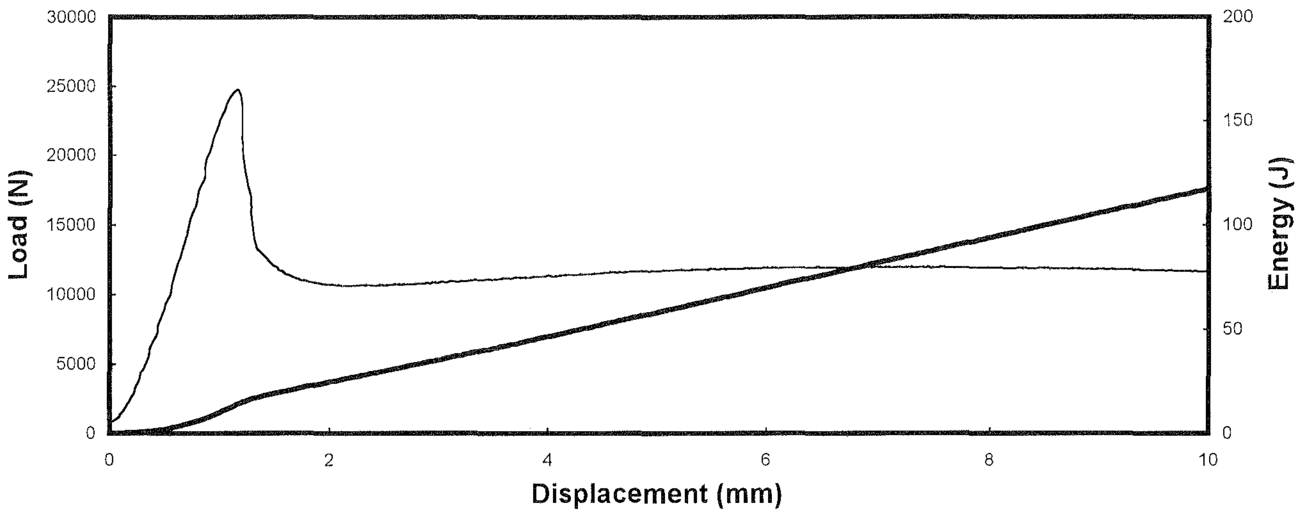
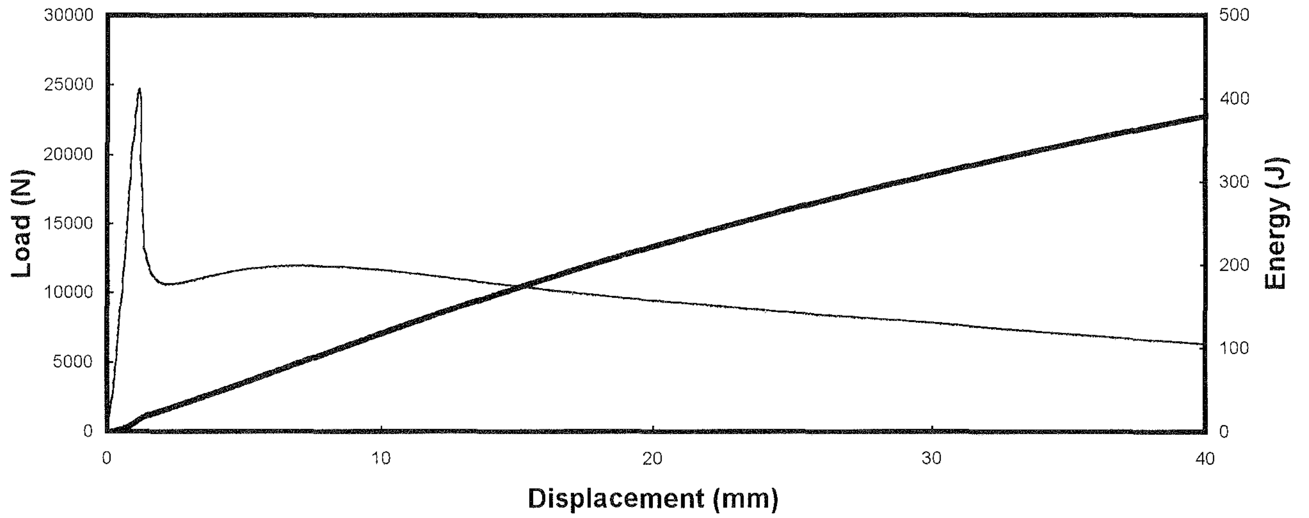
Round Determinate Panel Test Result

Specimen ID: V2-D16

Set: V2 Panel Set

Age: 110 day **Date:** 1/8/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
804	52	72
797	43	75
794	46	78
	37	77
	38	75
mean: 798.3	41	77
	42	79
	47	78
	51	75
	44	78
x:	44.1	76.4
cov:	11.3	2.8

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**24729** N	**23880** N
Energy at 5 mm	**58** J	**56** J
Energy at 10 mm	**117** J	**113** J
Energy at 20 mm	**222** J	**215** J
Energy at 40 mm	**379** J	**369** J

Performance corrections carried out according to Bernard and Pircher (2000)

2.2.3. Concrete Set 3

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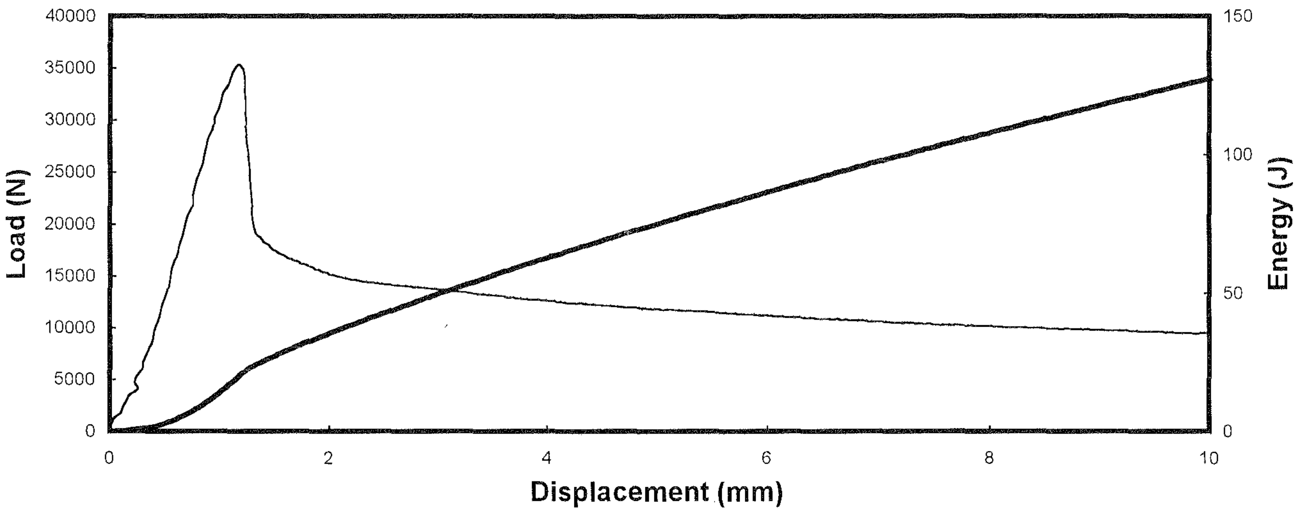
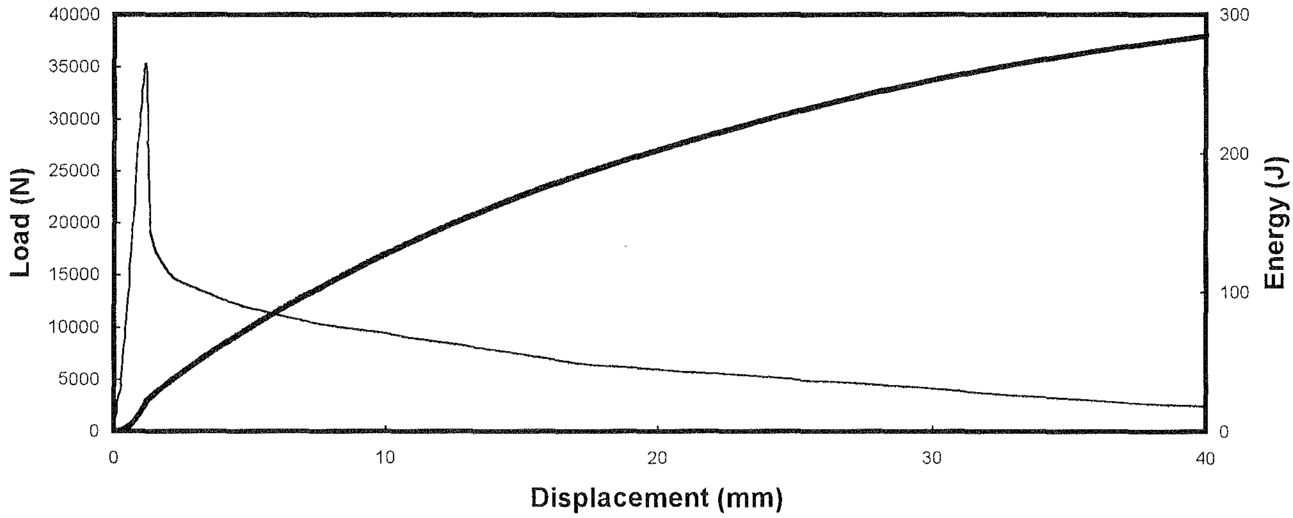
Round Determinate Panel Test Result

Specimen ID: V3-D01

Set: V3 Panel Set

Age: 56 days **Date:** 1/11/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
805	9	77
804	10	77
802	20	76
	17	75
	26	75
mean: 803.7	18	75
	16	75
	19	78
	12	76
	14	77
	x: 16.1	76.1
	cov: 31.7	1.4

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**35357** N	**34186** N
Energy at 5 mm	**75** J	**72** J
Energy at 10 mm	**127** J	**123** J
Energy at 20 mm	**202** J	**196** J
Energy at 40 mm	**284** J	**277** J

Performance corrections carried out according to Bernard and Pircher (2000)

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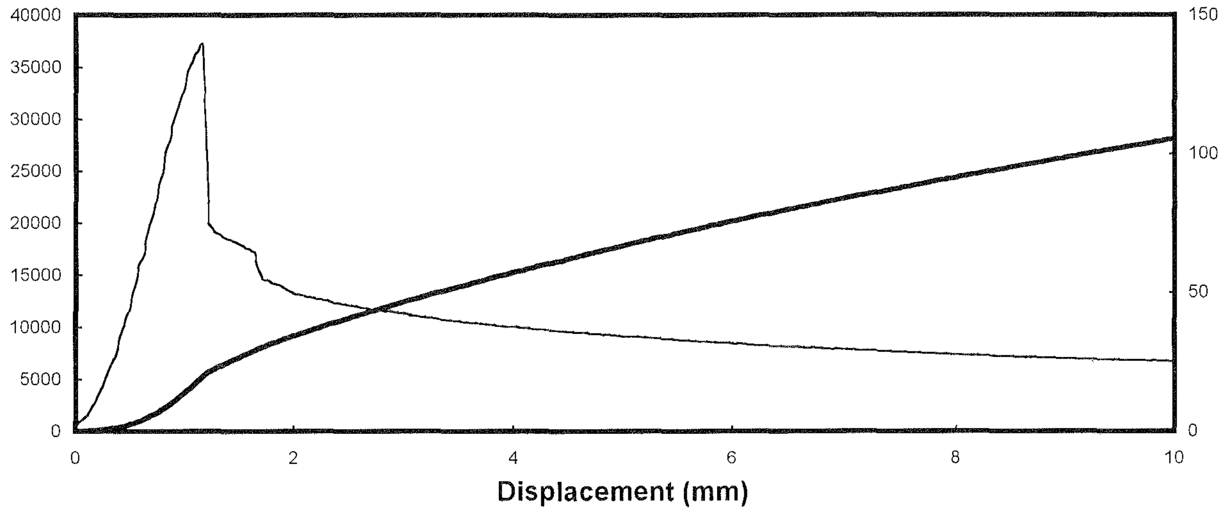
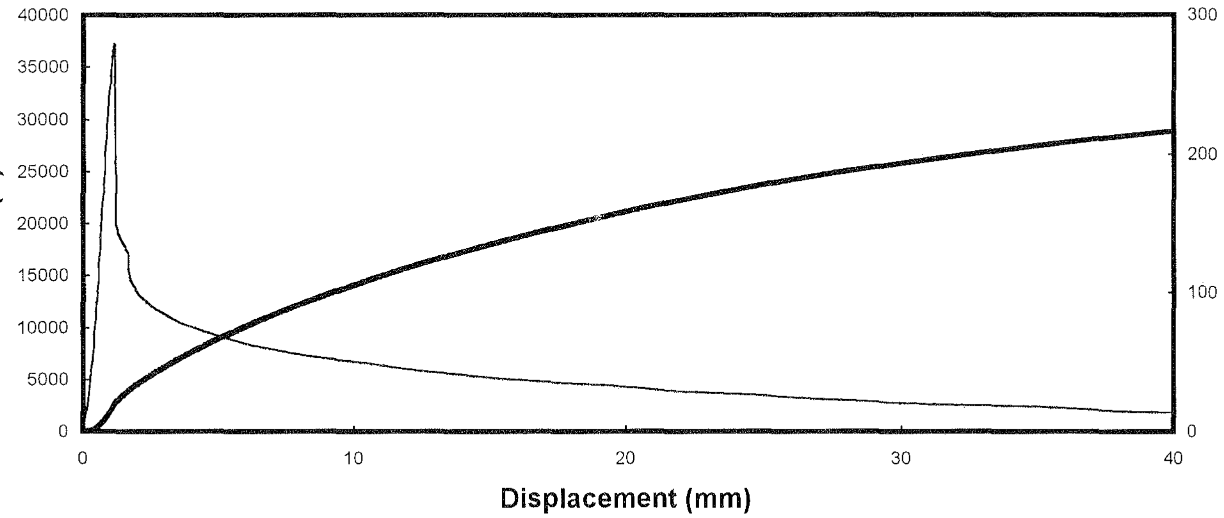
Round Determinate Panel Test Result **Specimen ID:** V3-D02

Set: V3 Panel Set **Age:** 56 days **Date:** 1/11/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
804	14	78
803	15	78
804	9	76
	14	76
	19	75
mean: 803.7	9	78
	15	76
	15	77
	13	79
	7	76
	x: 13	76.9
	cov: 27.9	1.7

Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**37209** N	**35232** N
Energy at 5 mm	**67** J	**63** J
Energy at 10 mm	**105** J	**100** J
Energy at 20 mm	**158** J	**151** J
Energy at 40 mm	**216** J	**207** J

Performance corrections carried out according to Bernard and Pircher (2000)

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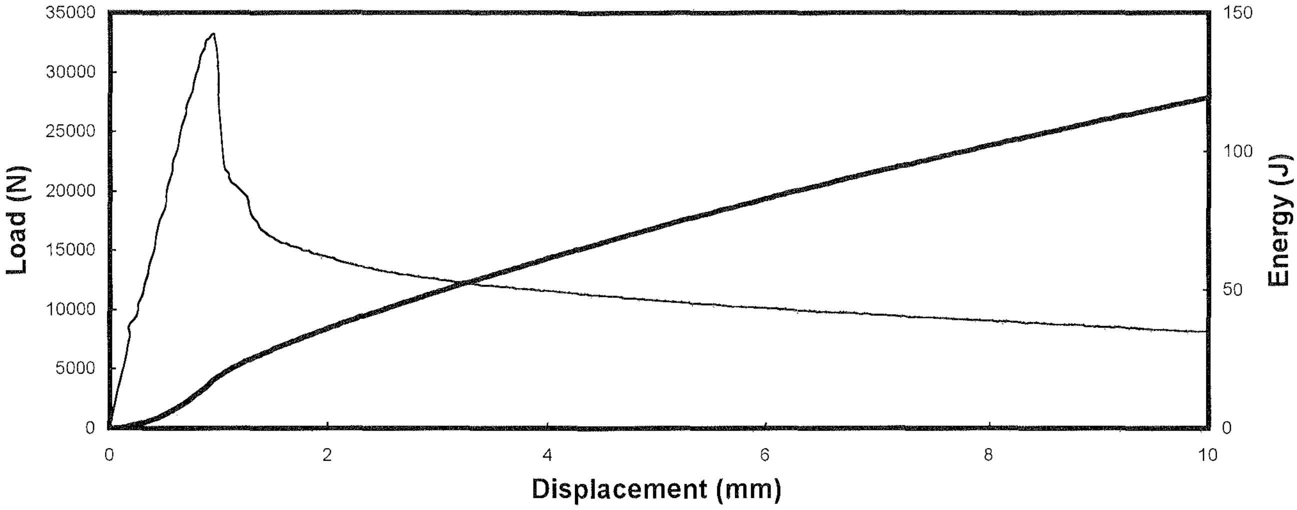
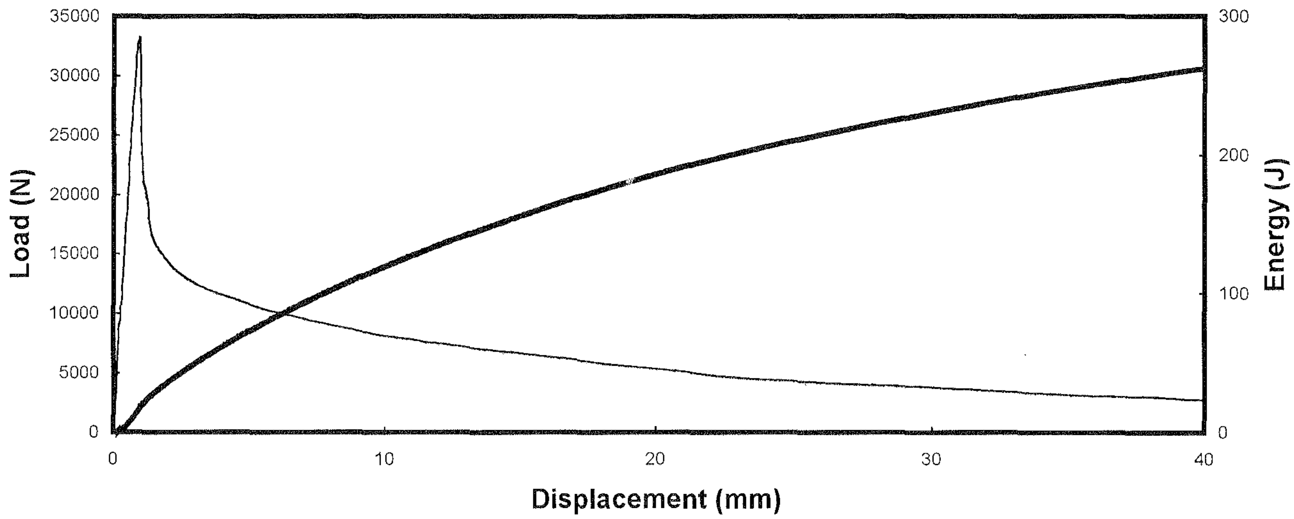
Round Determinate Panel Test Result **Specimen ID:** V3-D03

Set: V3 Panel Set **Age:** 56 days **Date:** 1/11/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
801	13	75
803	9	75
804	11	77
	8	76
	12	76
mean: 802.7	24	76
	15	78
	18	75
	17	75
	12	79
	x: 13.9	76.2
	cov: 34.3	1.8

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**33273** N	**32126** N
Energy at 5 mm	**72** J	**70** J
Energy at 10 mm	**119** J	**115** J
Energy at 20 mm	**186** J	**180** J
Energy at 40 mm	**262** J	**255** J

Performance corrections carried out according to Bernard and Pircher (2000)

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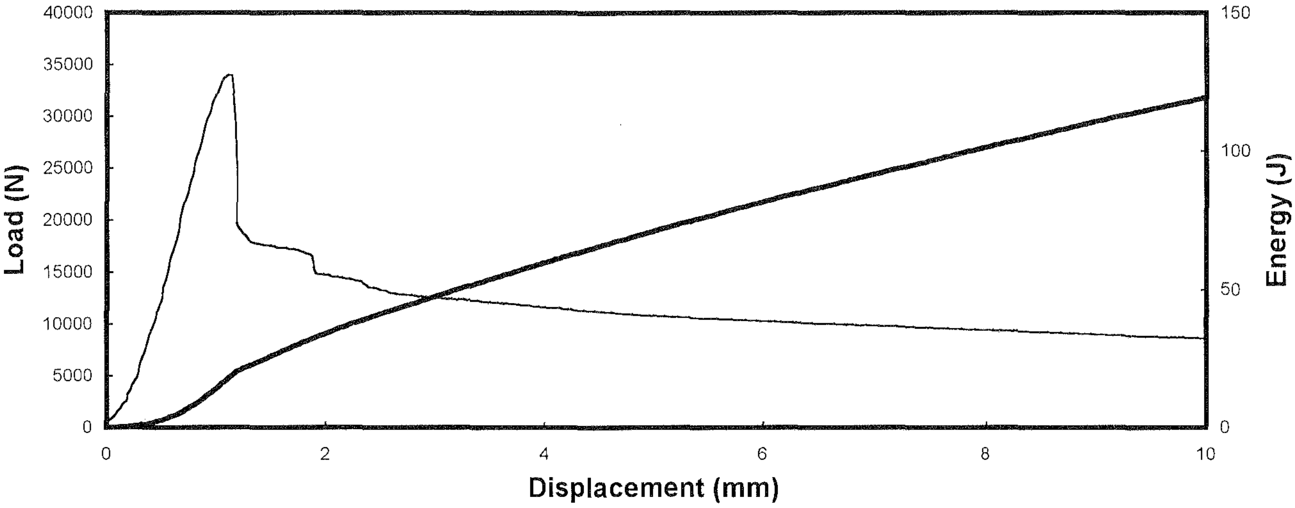
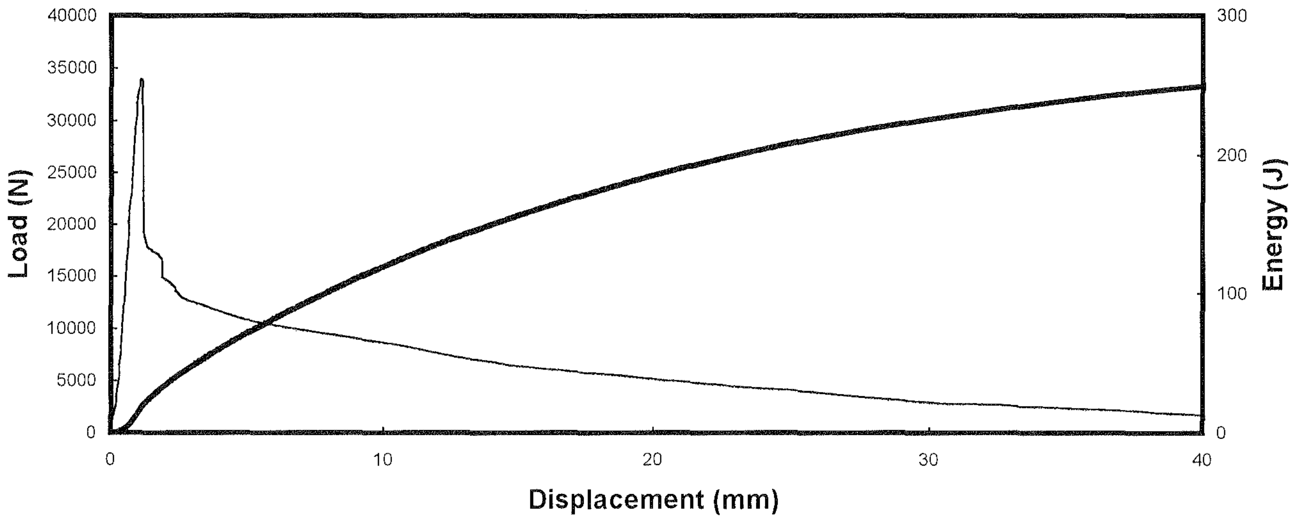
Round Determinate Panel Test Result **Specimen ID:** V3-D04

Set: V3 Panel Set **Age:** 56 days **Date:** 1/11/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
794	17	75
797	15	74
797	18	75
	19	75
	21	74
mean: 796.0	15	75
	12	76
	11	77
	14	74
	22	75
	x: 16.4	75.0
	cov: 22.3	1.3

Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**33988** N	**34159** N
Energy at 5 mm	**71** J	**71** J
Energy at 10 mm	**119** J	**120** J
Energy at 20 mm	**185** J	**186** J
Energy at 40 mm	**249** J	**251** J

Performance corrections carried out according to Bernard and Pircher (2000)

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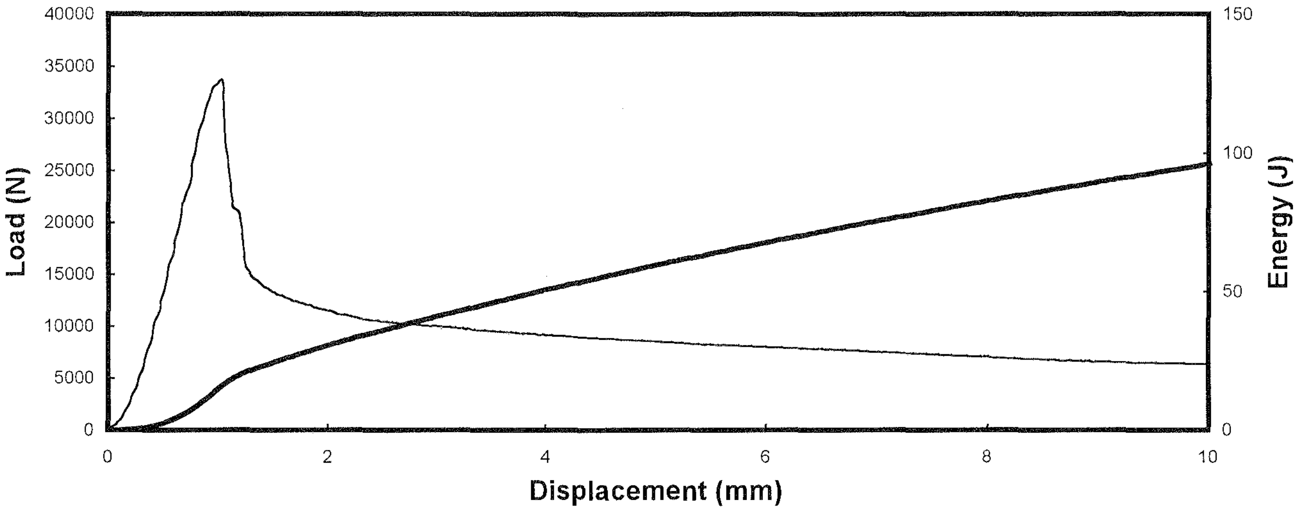
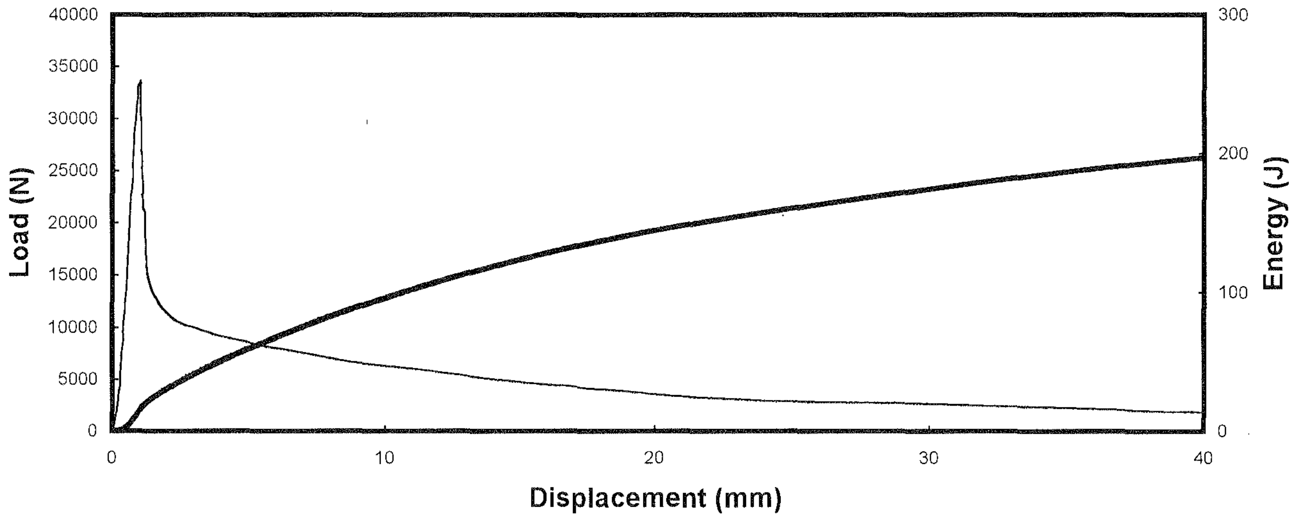
Round Determinate Panel Test Result **Specimen ID:** V3-D05

Set: V3 Panel Set **Age:** 56 days **Date:** 1/11/01





Specimen Dimensions

Diameter (mm)		Fibres	Thickness (mm)
797		15	79
797		13	79
802		15	79
		12	80
		11	78
mean:	798.7	13	76
		14	74
		12	76
		21	74
		14	76
	x:	14	77.1
	cov:	19.9	2.8

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**33652** N	**31897** N
Energy at 5 mm	**59** J	**56** J
Energy at 10 mm	**96** J	**91** J
Energy at 20 mm	**144** J	**138** J
Energy at 40 mm	**197** J	**189** J

Performance corrections carried out according to Bernard and Pircher (2000)

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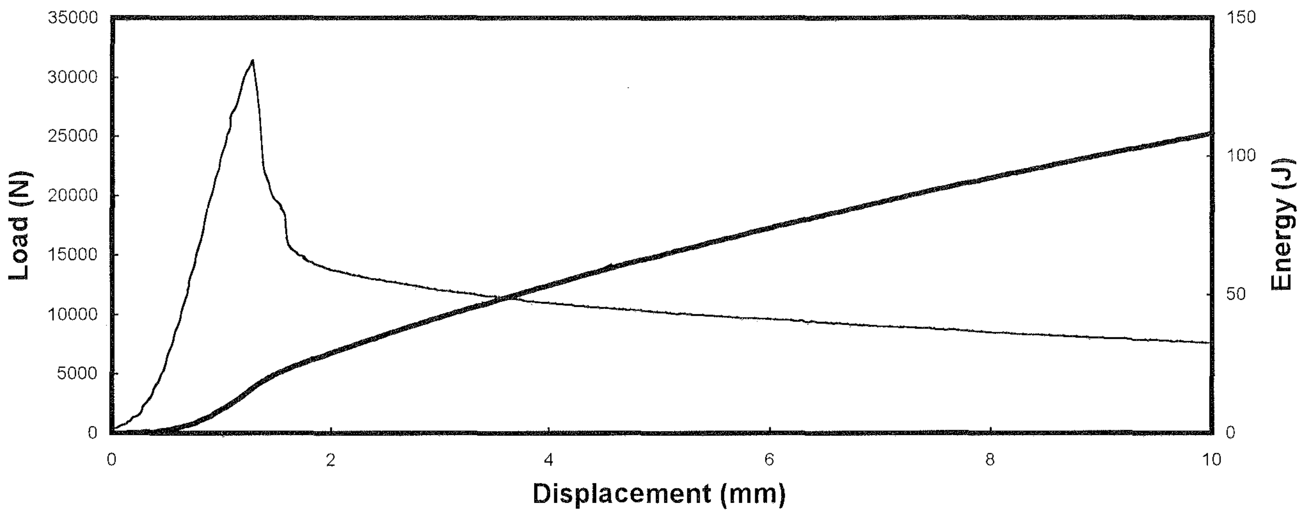
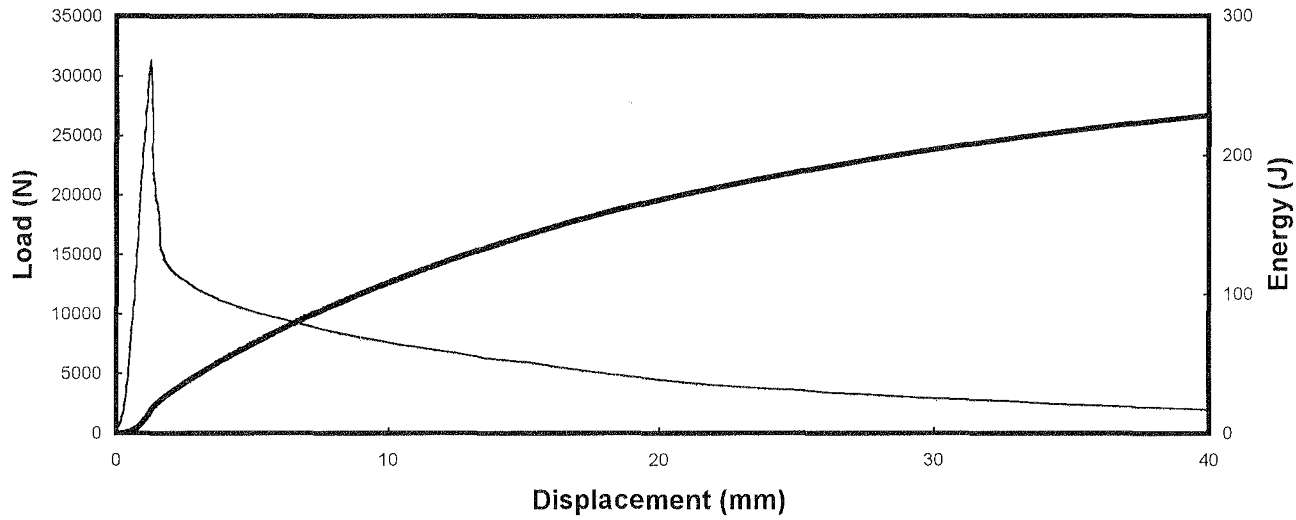
Round Determinate Panel Test Result **Specimen ID:** V3-D06

Set: V3 Panel Set **Age:** 56 days **Date:** 1/11/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
799	13	75
798	15	76
799	10	75
	16	74
	13	75
mean: 798.7	17	76
	15	75
	15	75
	9	76
	16	76
	x: 13.9	75.3
	cov: 19.0	0.9

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**31421** N	**31223** N
Energy at 5 mm	**64** J	**63** J
Energy at 10 mm	**108** J	**107** J
Energy at 20 mm	**168** J	**167** J
Energy at 40 mm	**229** J	**228** J

Performance corrections carried out according to Bernard and Pircher (2000)

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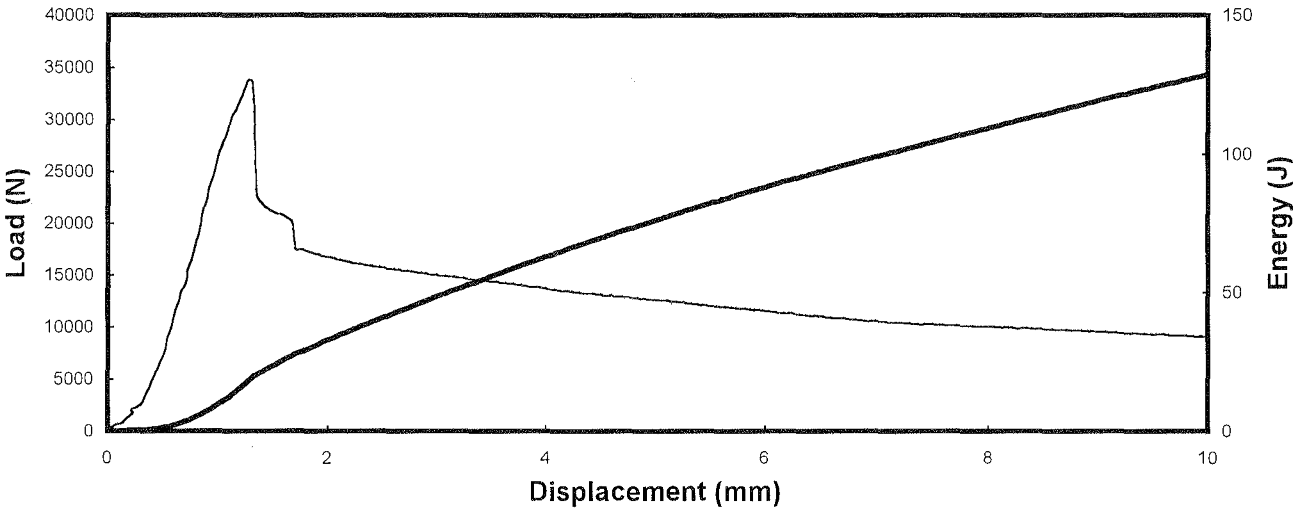
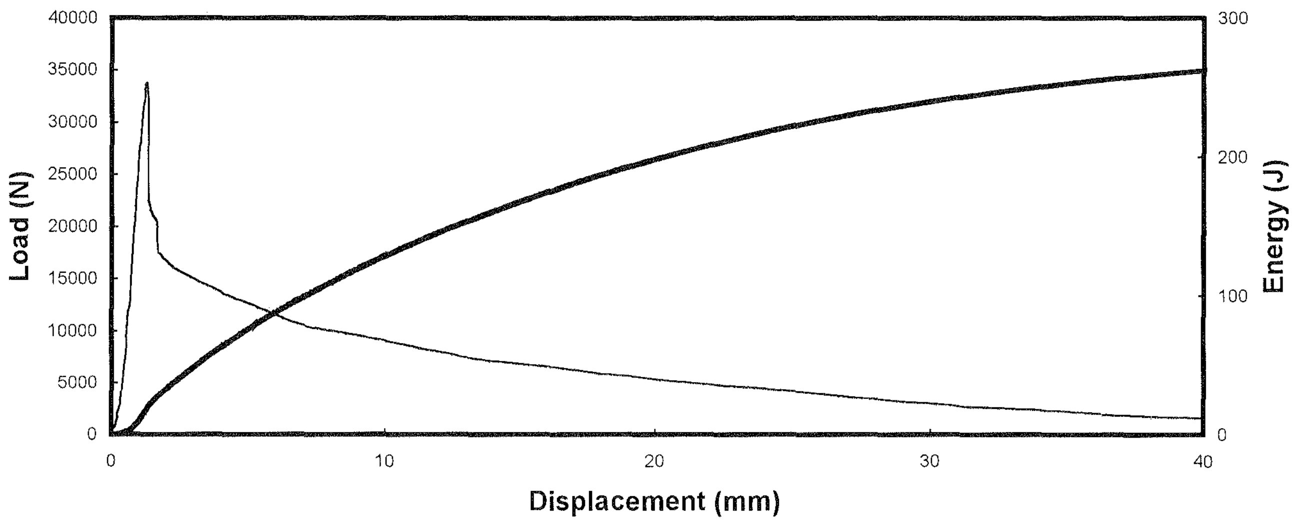
Round Determinate Panel Test Result

Specimen ID: V3-D07

Set: V3 Panel Set

Age: 56 days **Date:** 1/11/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
802	27	78
805	9	77
800	19	78
	17	77
	15	77
mean: 802.3	11	78
	14	77
	9	76
	15	75
	13	78
	x: 14.9	77.1
	cov: 35.9	1.3

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**33790** N	**31881** N
Energy at 5 mm	**76** J	**72** J
Energy at 10 mm	**128** J	**122** J
Energy at 20 mm	**198** J	**188** J
Energy at 40 mm	**262** J	**250** J

Performance corrections carried out according to Bernard and Pircher (2000)

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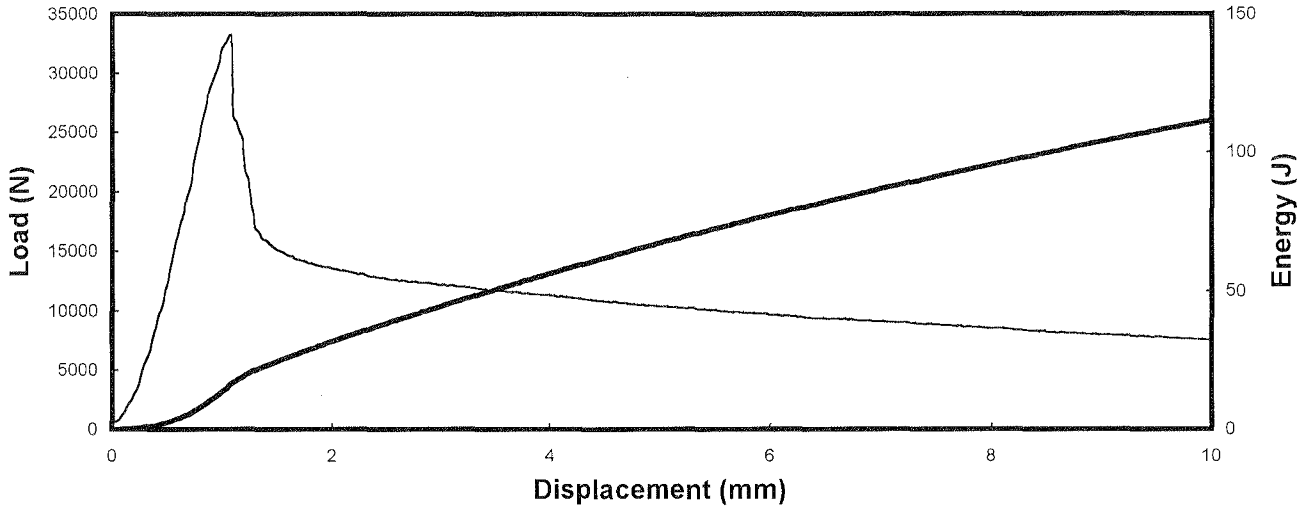
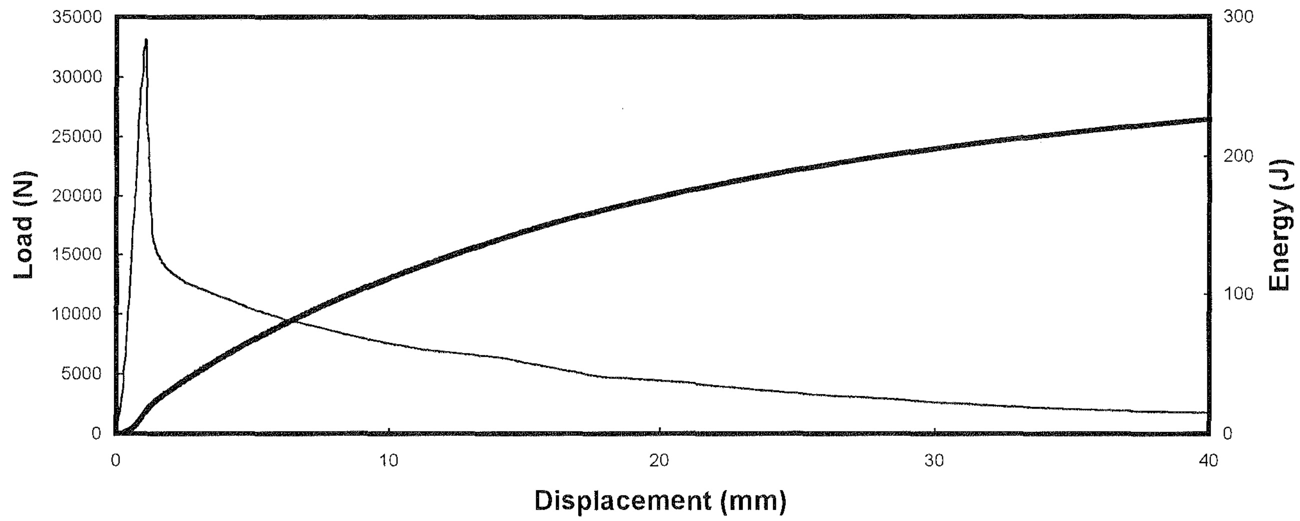
Round Determinate Panel Test Result — **Specimen ID:** V3-D08

Set: V3 Panel Set — **Age:** 56 days — **Date:** 1/11/01





Specimen Dimensions

Diameter (mm)		Fibres	Thickness (mm)
803		17	79
808		13	78
806		16	79
		18	79
		14	79
mean:	805.7	19	75
		15	76
		3	77
		15	80
		14	76
	x:	14.4	77.8
	cov:	30.7	2.2

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**33195** N	**30632** N
Energy at 5 mm	**67** J	**62** J
Energy at 10 mm	**111** J	**103** J
Energy at 20 mm	**170** J	**159** J
Energy at 40 mm	**226** J	**213** J

Performance corrections carried out according to Bernard and Pircher (2000)

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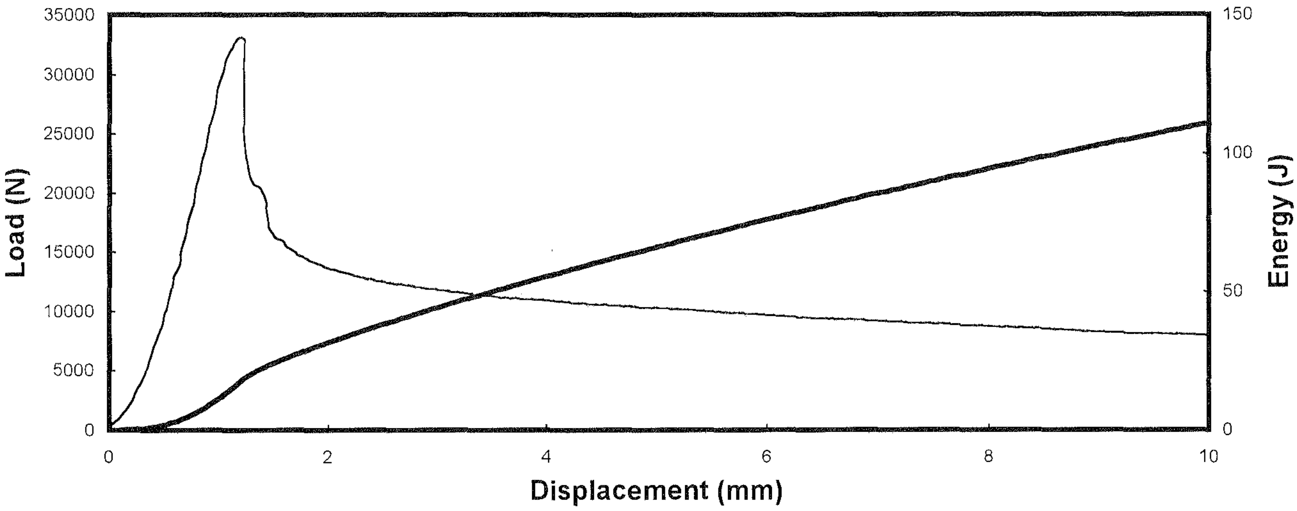
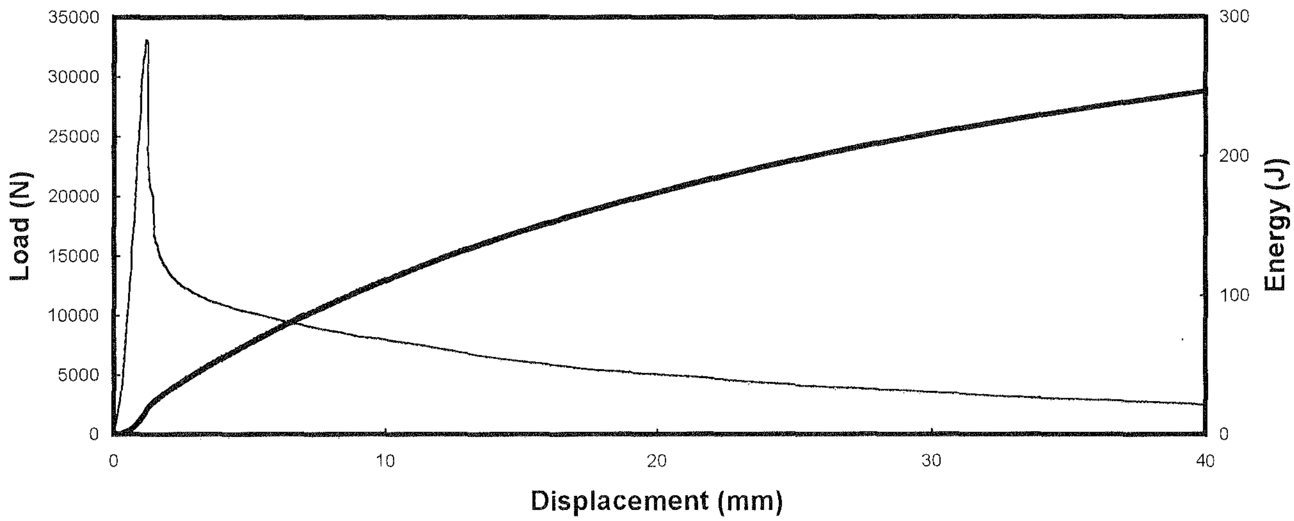
Round Determinate Panel Test Result **Specimen ID:** V3-D09

Set: V3 Panel Set **Age:** 56 days **Date:** 1/11/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
804	14	78
803	22	79
807	13	77
	11	78
	12	78
mean: 804.7	10	76
	13	77
	10	75
	18	75
	14	75
	x: 13.7	76.8
	cov: 27.3	1.9

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**33135** N	**31417** N
Energy at 5 mm	**66** J	**62** J
Energy at 10 mm	**111** J	**105** J
Energy at 20 mm	**174** J	**166** J
Energy at 40 mm	**246** J	**236** J

Performance corrections carried out according to Bernard and Pircher (2000)

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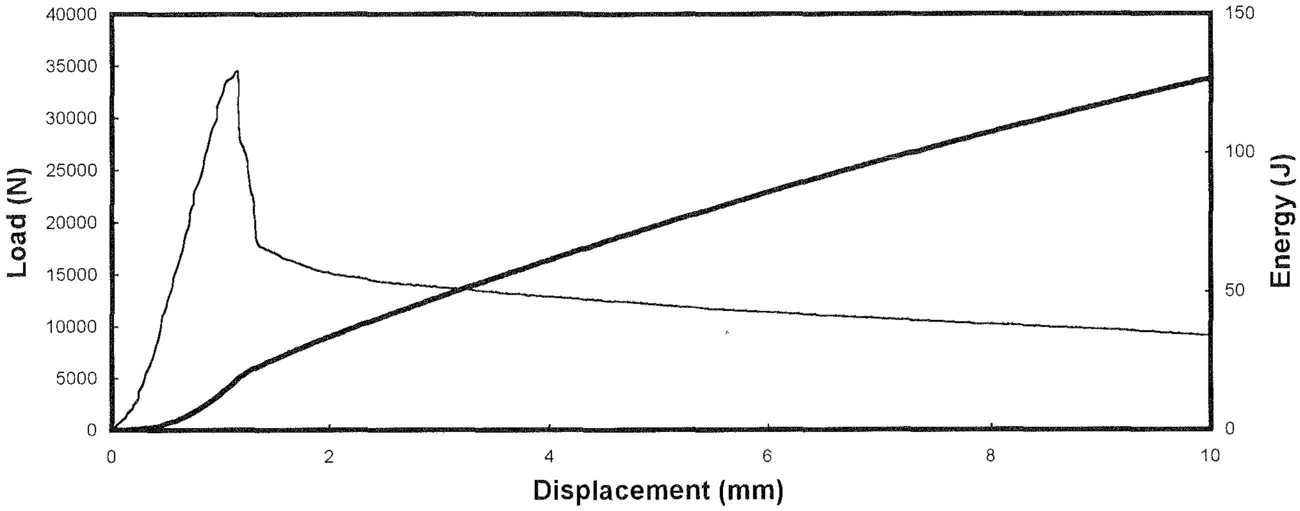
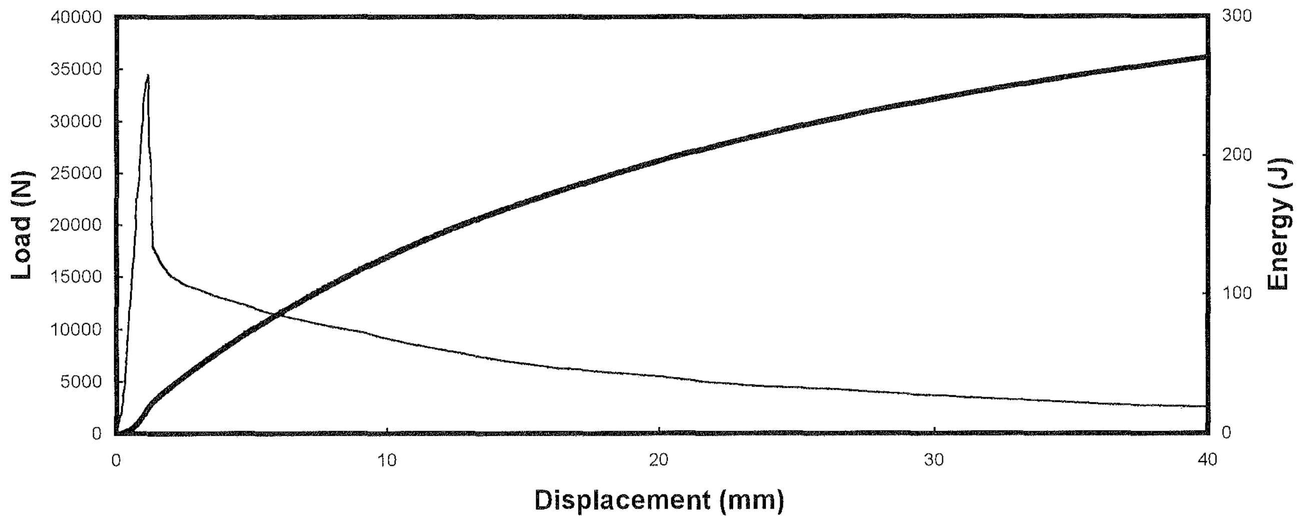
Round Determinate Panel Test Result **Specimen ID:** V3-D10

Set: V3 Panel Set **Age:** 56 days **Date:** 1/11/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
797	18	75
787	11	76
800	20	74
	15	76
	18	77
mean: 794.7	15	76
	14	76
	12	74
	27	76
	18	74
	x: 16.8	75.4
	cov: 27.3	1.4

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

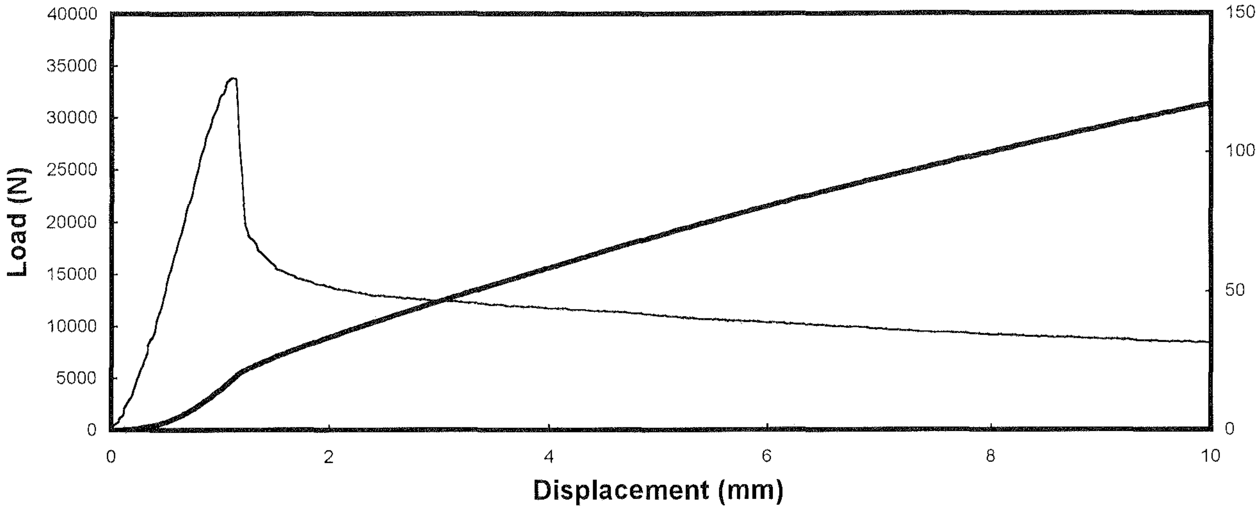
Parameter	Raw Results	Corrected
Peak Load (N)	**34496** N	**34360** N
Energy at 5 mm	**74** J	**74** J
Energy at 10 mm	**126** J	**126** J
Energy at 20 mm	**196** J	**195** J
Energy at 40 mm	**271** J	**270** J

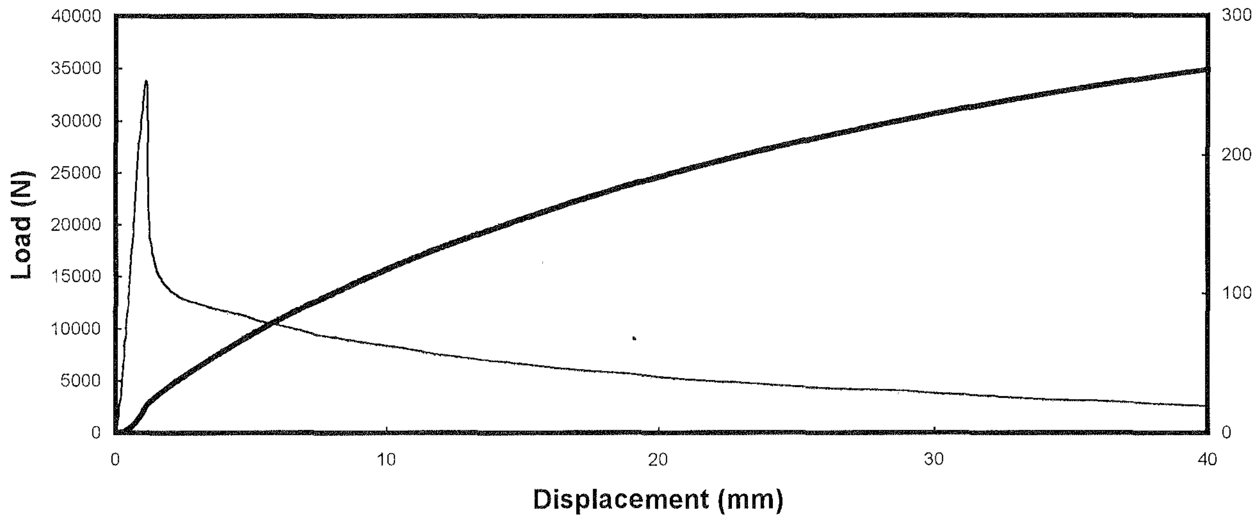
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V3-D11

Set: V3 Panel Set **Age:** 56 days **Date:** 1/12/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
794	22	78
800	16	78
794	25	79
	17	77
	19	79
mean: 796.0	10	78
	23	79
	16	74
	13	75
	18	74
x:	17.9	77.1
cov:	25.6	2.6

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

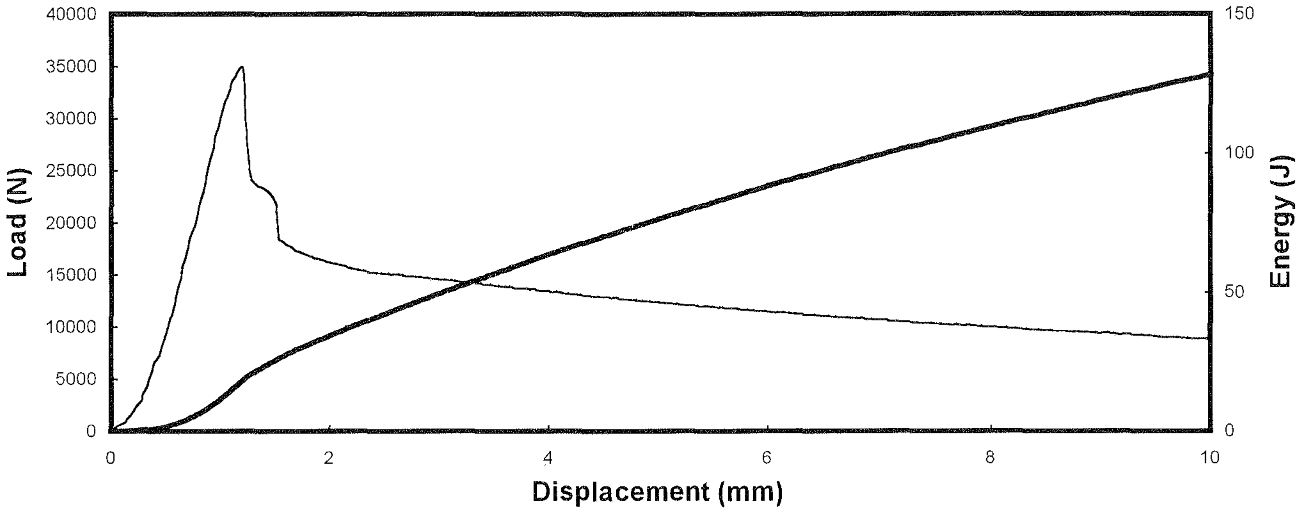
Parameter	Raw Results	Corrected
Peak Load (N)	33850 N	32192 N
Energy at 5 mm	70 J	66 J
Energy at 10 mm	117 J	112 J
Energy at 20 mm	184 J	176 J
Energy at 40 mm	261 J	252 J

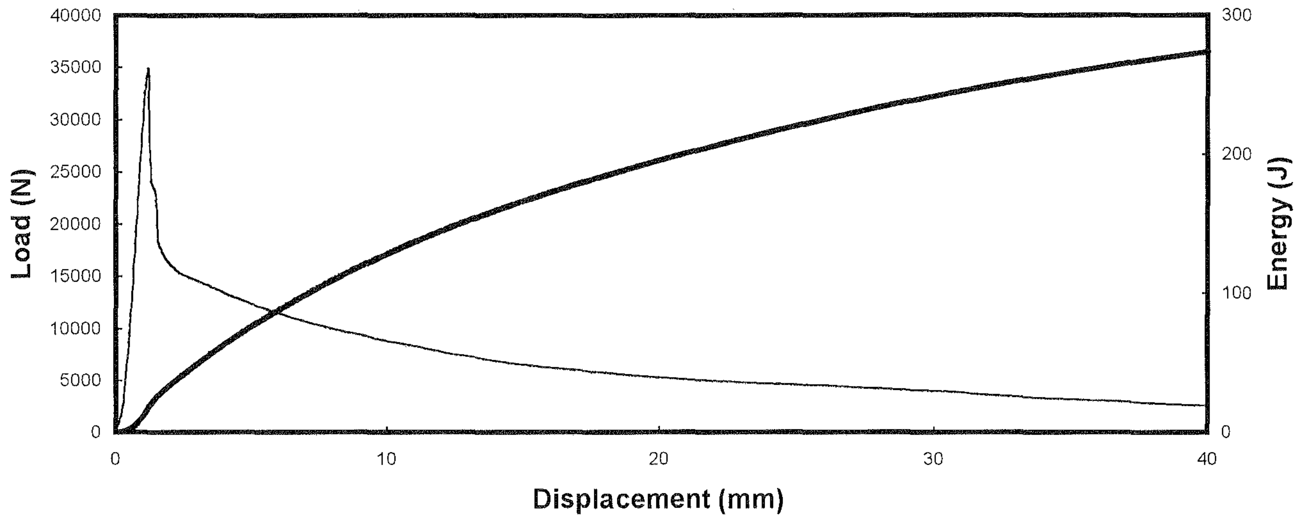
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V3-D12

Set: V3 Panel Set **Age:** 56 days **Date:** 1/12/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
798	14	80
803	7	79
803	24	79
	13	80
	16	81
mean: 801.3	14	74
	23	75
	17	75
	14	75
	18	74
	x: 16	77.2
	cov: 30.9	3.7

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**34995** N	**32974** N
Energy at 5 mm	**76** J	**72** J
Energy at 10 mm	**128** J	**121** J
Energy at 20 mm	**195** J	**185** J
Energy at 40 mm	**273** J	**261** J

Performance corrections carried out according to Bernard and Pircher (2000)

2.2.4. Concrete Set 4

University of Western Sydney
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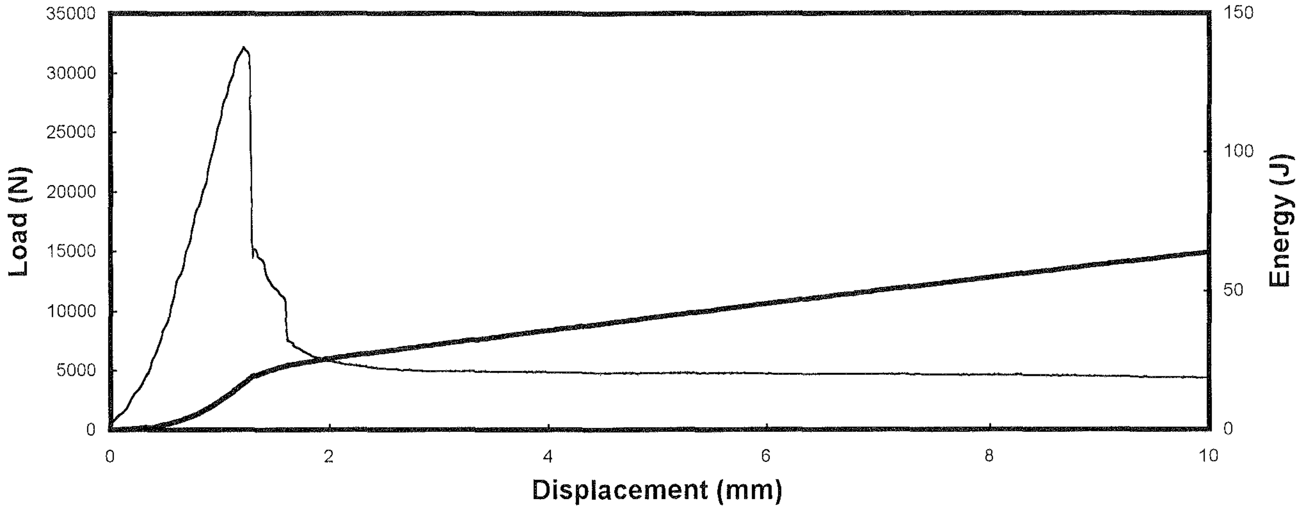
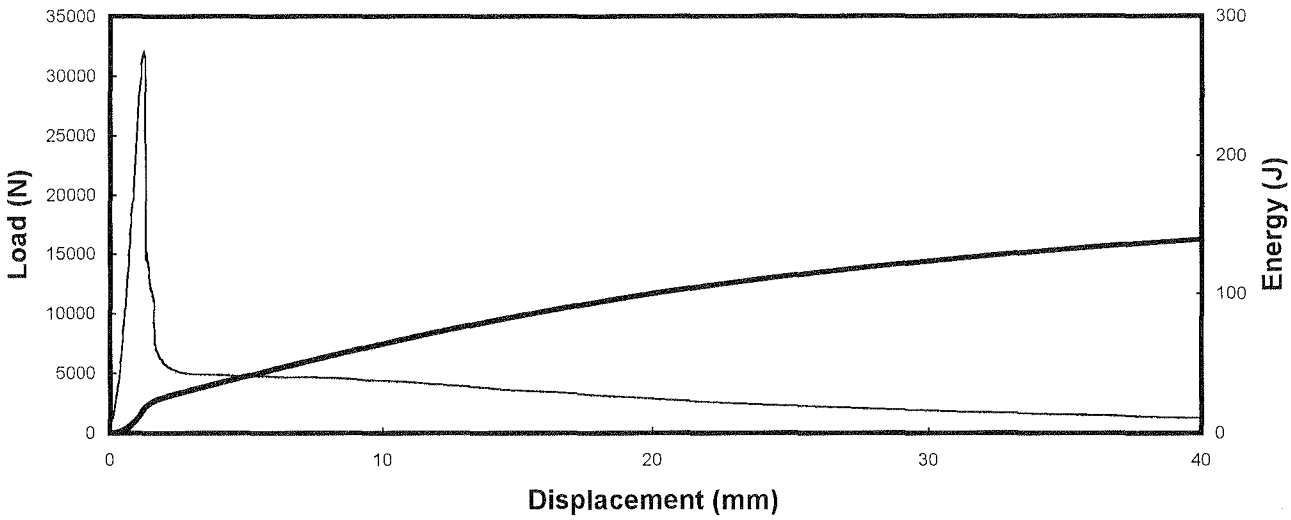
Round Determinate Panel Test Result

Specimen ID: V4-D01

Set: V4 Panel Set

Age: 56 days **Date:** 1/29/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
794	12	78
792	13	79
786	6	78
	23	78
	18	78
mean: 790.7	8	75
	12	77
	10	77
	8	78
	6	77
	x: 11.6	77.5
	cov: 46.7	1.4

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	32196 N	30508 N
Energy at 5 mm	41 J	38 J
Energy at 10 mm	64 J	61 J
Energy at 20 mm	100 J	96 J
Energy at 40 mm	139 J	134 J

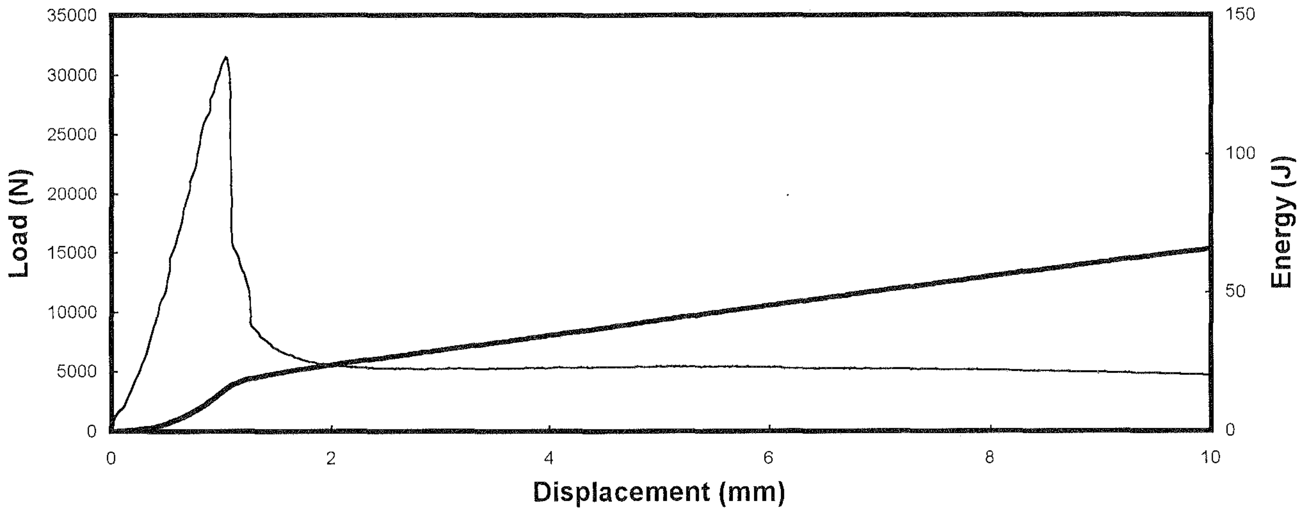
Performance corrections carried out according to Bernard and Pircher (2000)

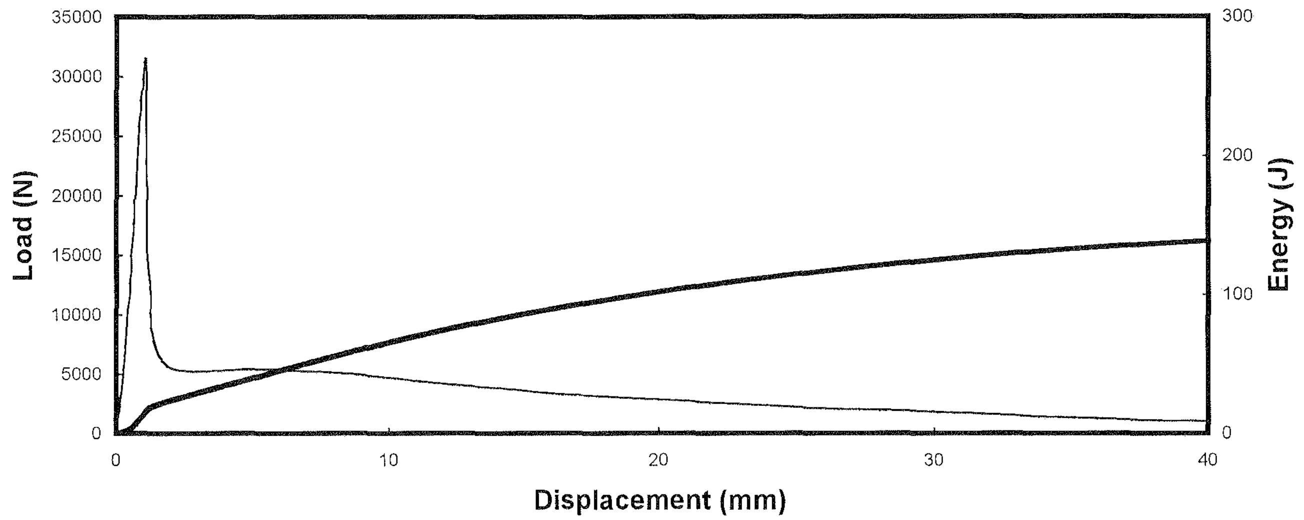
University of Western Sydney

School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V4-D02

Set: V4 Panel Set **Age:** 56 days **Date:** 1/29/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
798	18	77
793	16	76
800	7	77
	11	78
	15	78
mean: 797.0	16	73
	12	75
	20	78
	9	81
	9	77
	x: 13.3	77.0
	cov: 32.5	2.7

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

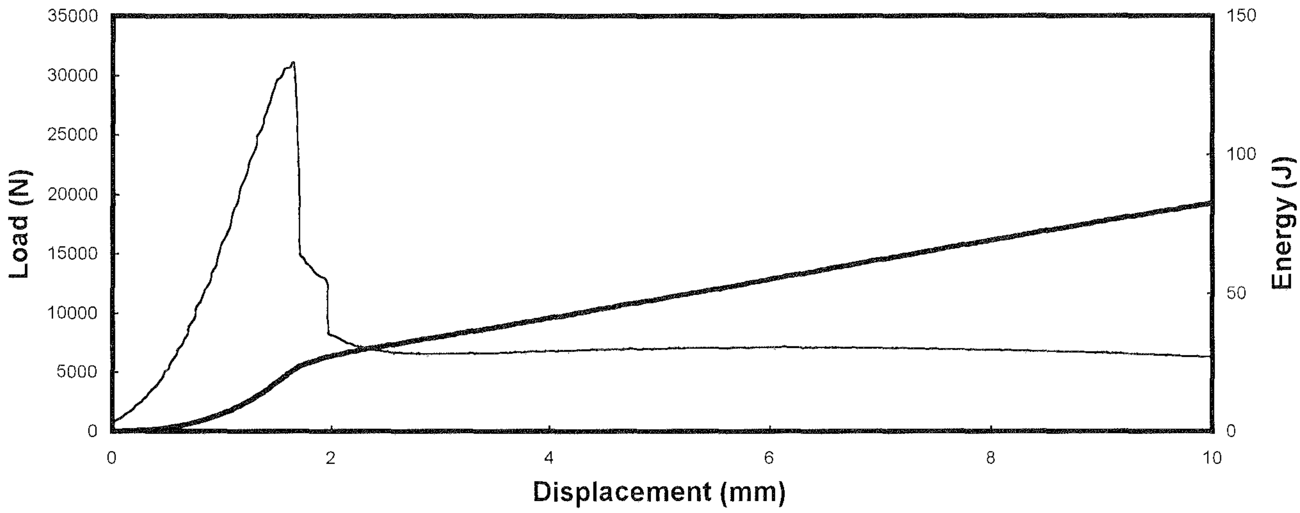
Parameter	Raw Results	Corrected
Peak Load (N)	**31559** N	**30053** N
Energy at 5 mm	**40** J	**38** J
Energy at 10 mm	**65** J	**63** J
Energy at 20 mm	**102** J	**98** J
Energy at 40 mm	**139** J	**134** J

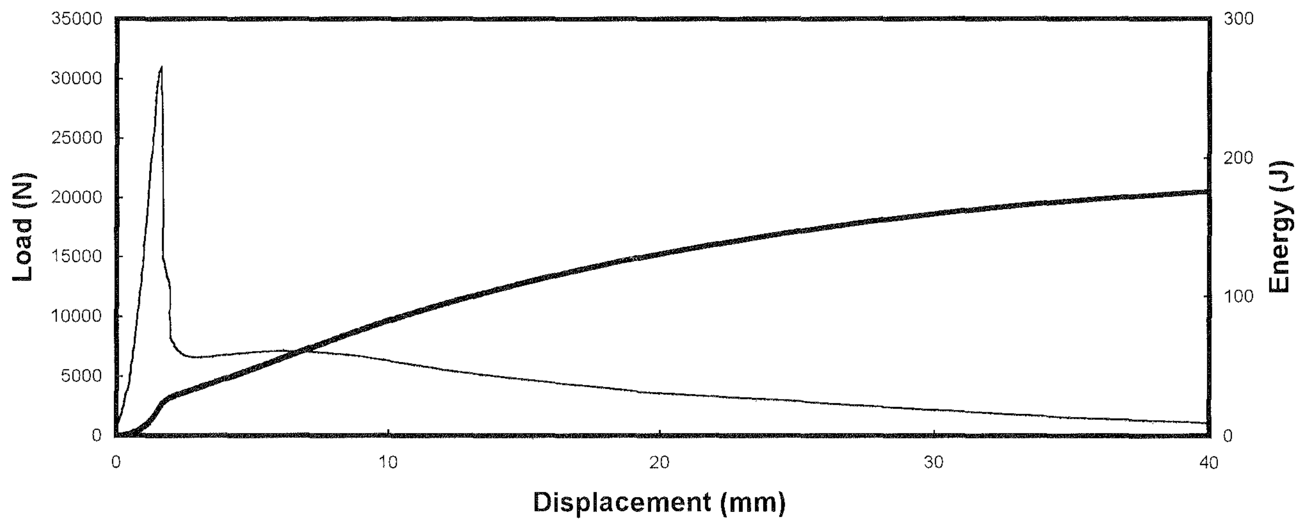
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V4-D03

Set: V4 Panel Set **Age:** 56 days **Date:** 1/29/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
797	12	78
800	11	79
800	6	77
	14	77
	12	78
mean: 799.0	18	79
	10	79
	13	78
	6	75
	7	77
	x: 10.9	77.7
	cov: 35.0	1.6

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

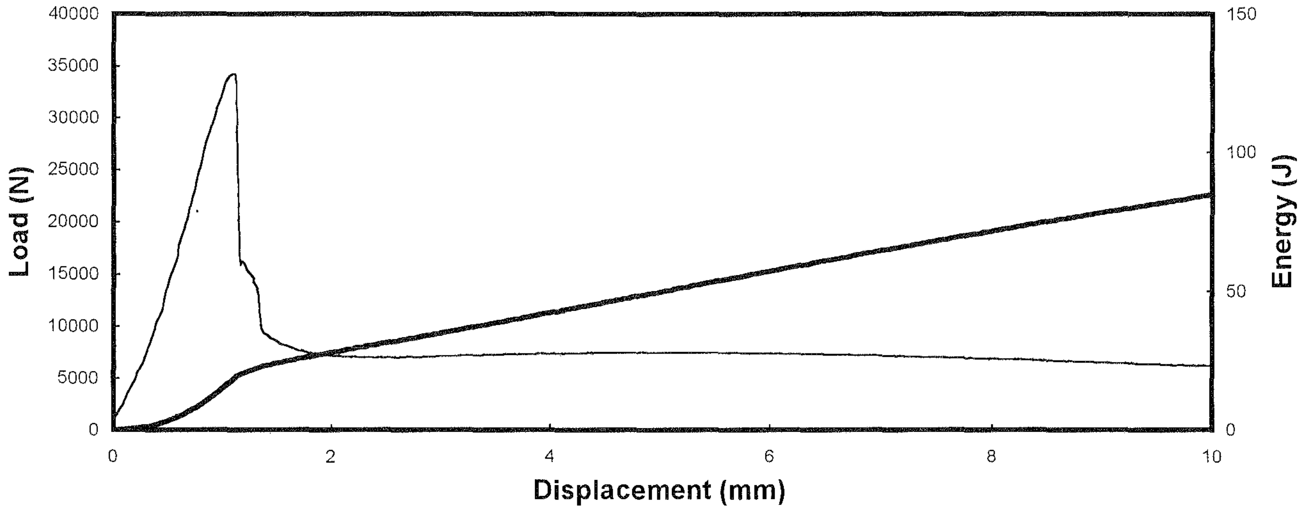
Parameter	Raw Results	Corrected
Peak Load (N)	**31051** N	**28966** N
Energy at 5 mm	**48** J	**45** J
Energy at 10 mm	**82** J	**77** J
Energy at 20 mm	**130** J	**123** J
Energy at 40 mm	**175** J	**166** J

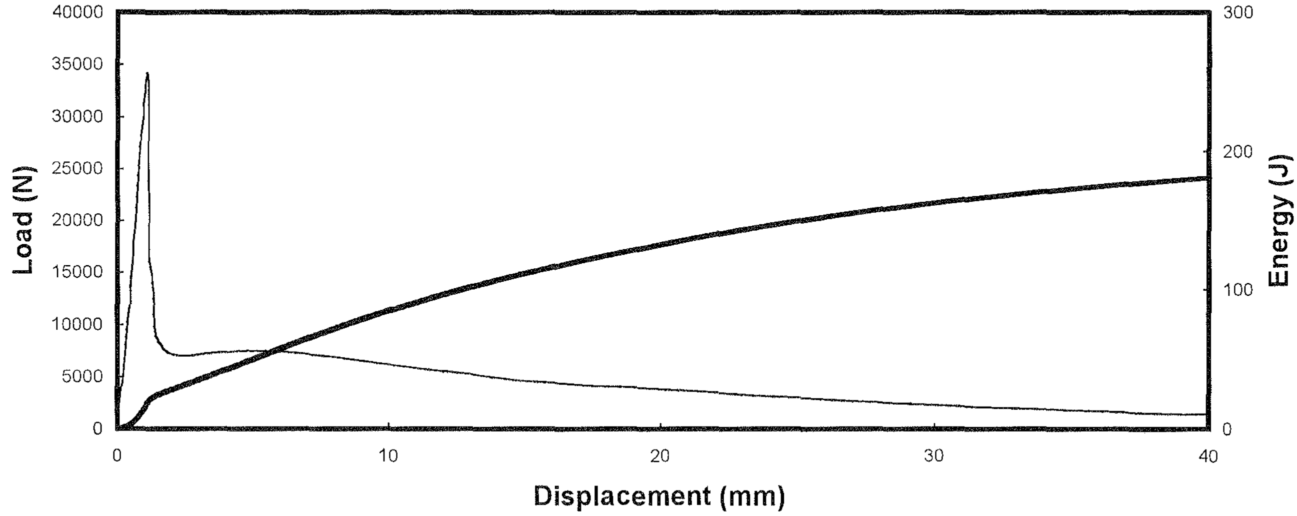
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V4-D04

Set: V4 Panel Set **Age:** 56 days **Date:** 1/29/01





Specimen Dimensions

Diameter (mm)		Fibres	Thickness (mm)
794		22	79
795		11	79
798		21	78
		15	80
		11	80
mean: 795.7		6	80
		12	78
		15	78
		21	75
		12	75
	x:	14.6	78.2
	cov:	36.1	2.4

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

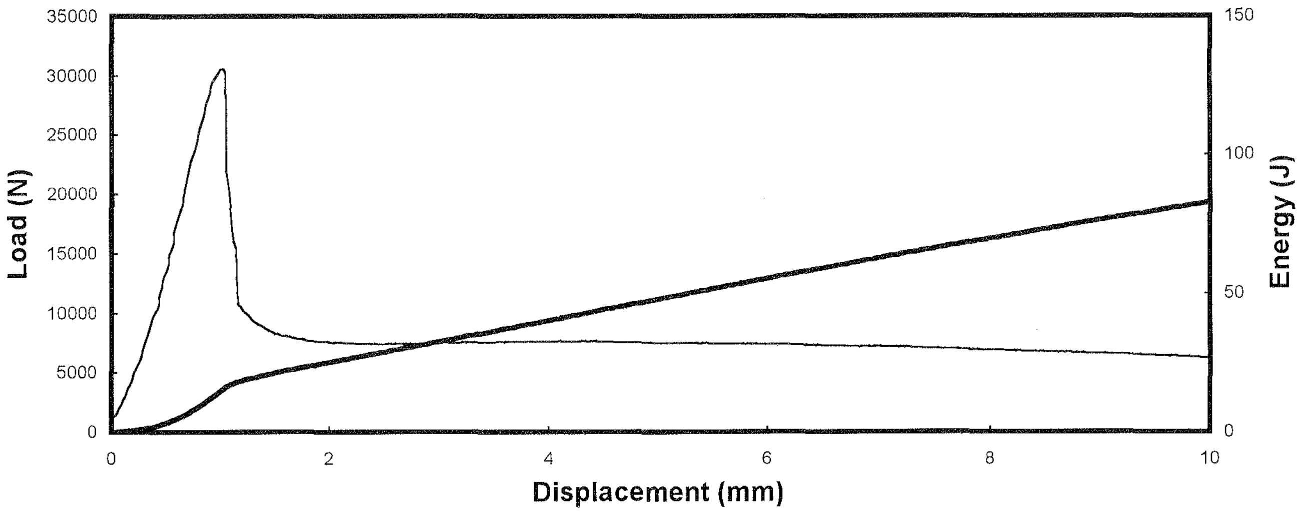
Parameter	Raw Results	Corrected
Peak Load (N)	**34203** N	**31632** N
Energy at 5 mm	**50** J	**46** J
Energy at 10 mm	**84** J	**79** J
Energy at 20 mm	**132** J	**124** J
Energy at 40 mm	**181** J	**171** J

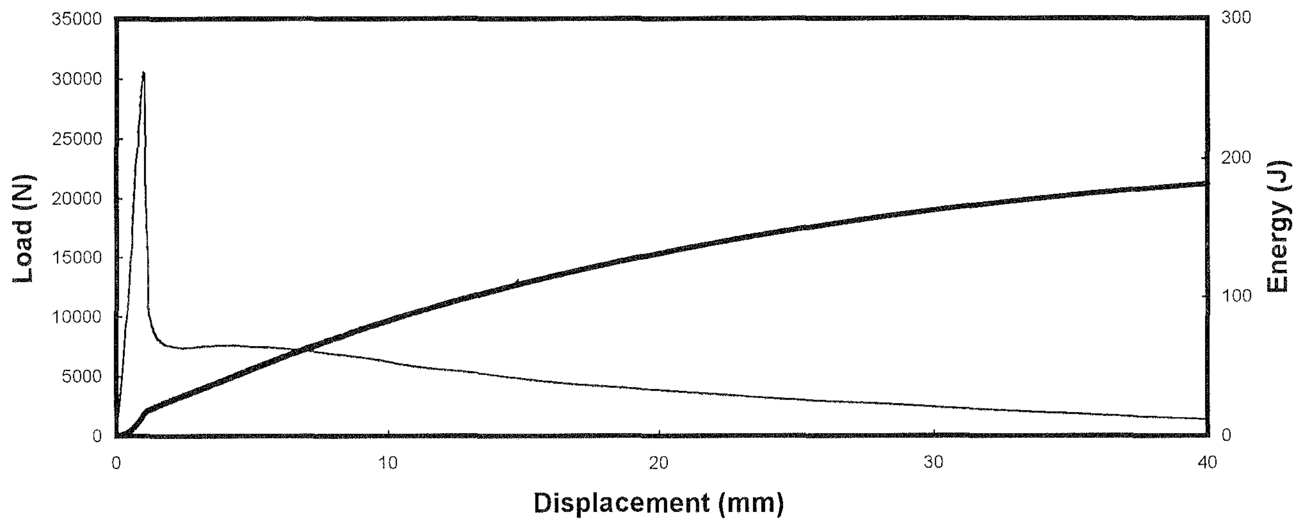
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V4-D05

Set: V4 Panel Set **Age:** 56 days **Date:** 1/29/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
797	18	75
796	18	75
800	11	76
	11	74
	16	75
mean: 797.7	12	75
	20	75
	15	76
	12	74
	9	75
x:	14.2	75.0
cov:	26.1	0.9

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**30594** N	**30684** N
Energy at 5 mm	**48** J	**48** J
Energy at 10 mm	**83** J	**83** J
Energy at 20 mm	**131** J	**132** J
Energy at 40 mm	**181** J	**182** J

Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
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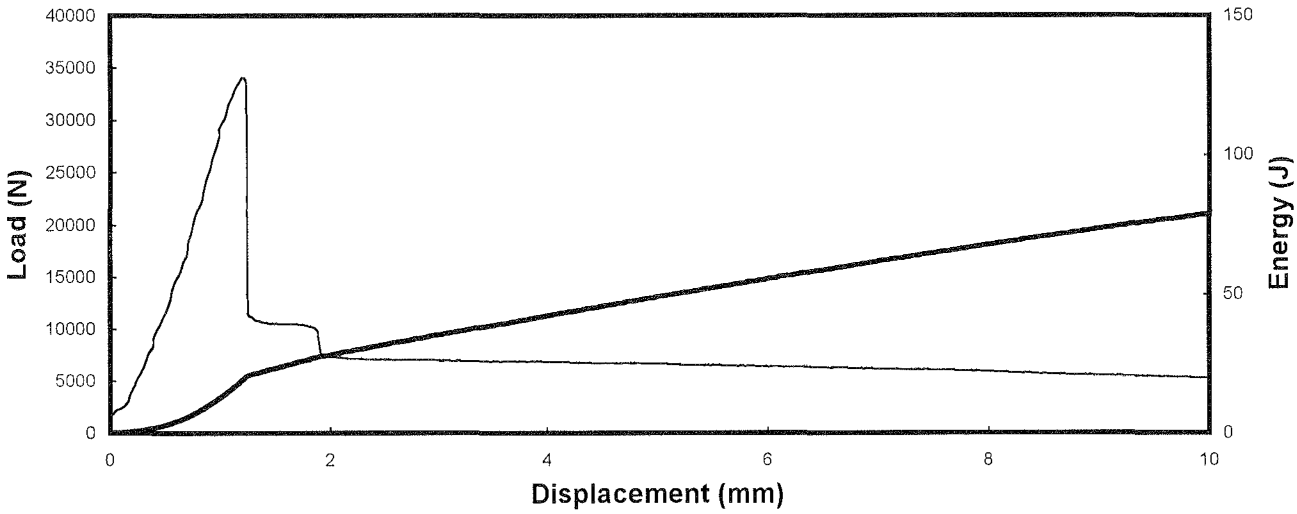
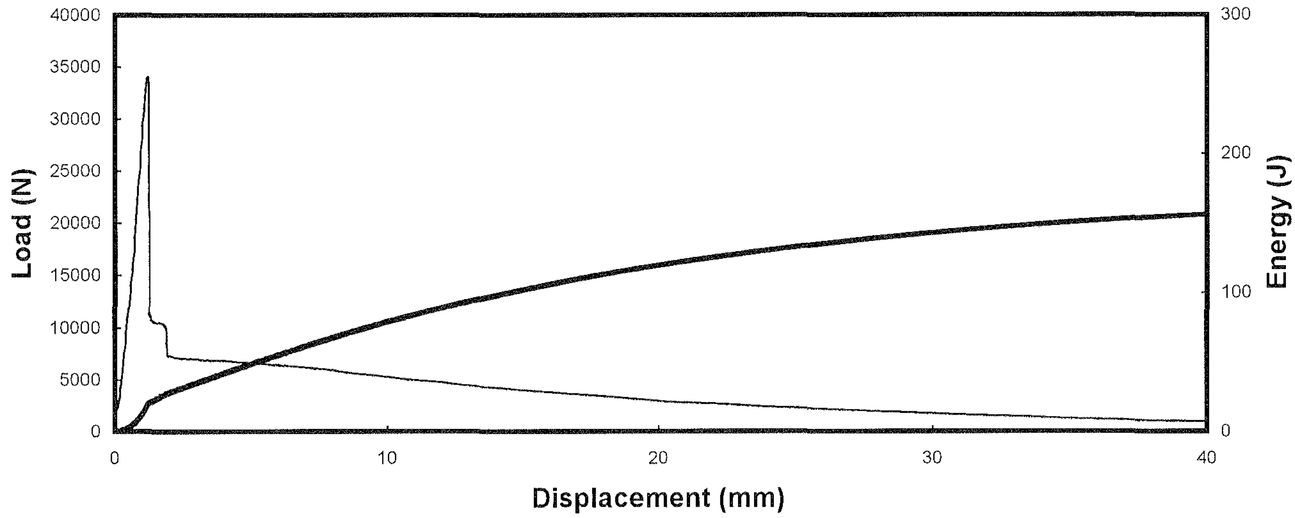
Round Determinate Panel Test Result

Specimen ID: V4-D06

Set: V4 Panel Set

Age: 56 days **Date:** 1/29/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
797	15	77
802	21	77
804	13	78
	14	78
	11	77
mean: 801.0	13	75
	8	77
	17	76
	12	75
	13	77
x:	13.7	76.7
cov:	25.5	1.4

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

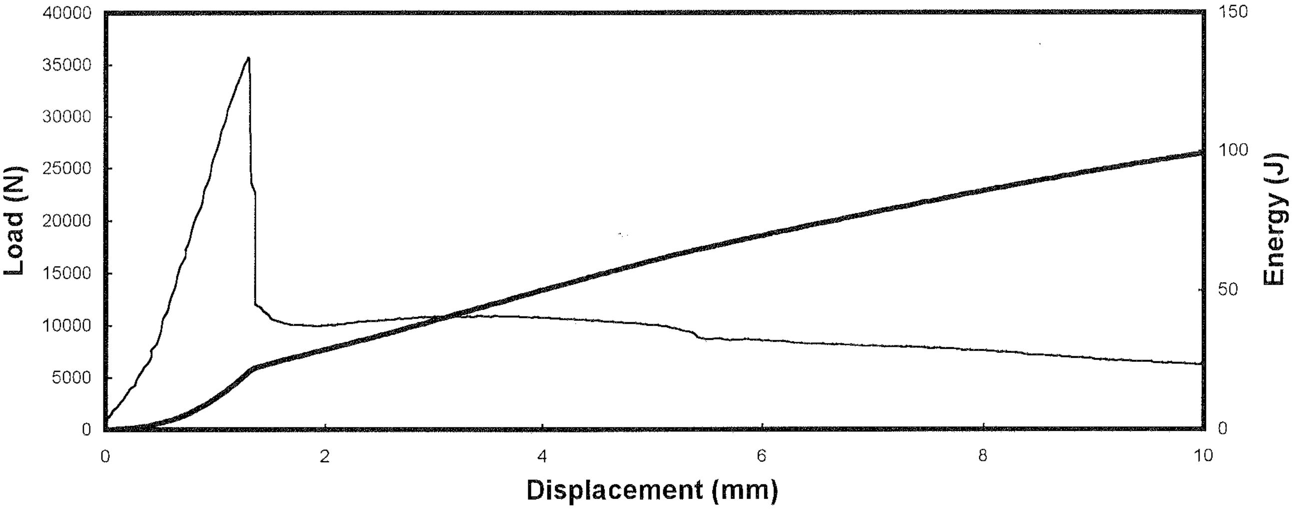
Parameter	Raw Results	Corrected
Peak Load (N)	34108 N	32572 N
Energy at 5 mm	49 J	47 J
Energy at 10 mm	79 J	75 J
Energy at 20 mm	119 J	115 J
Energy at 40 mm	156 J	150 J

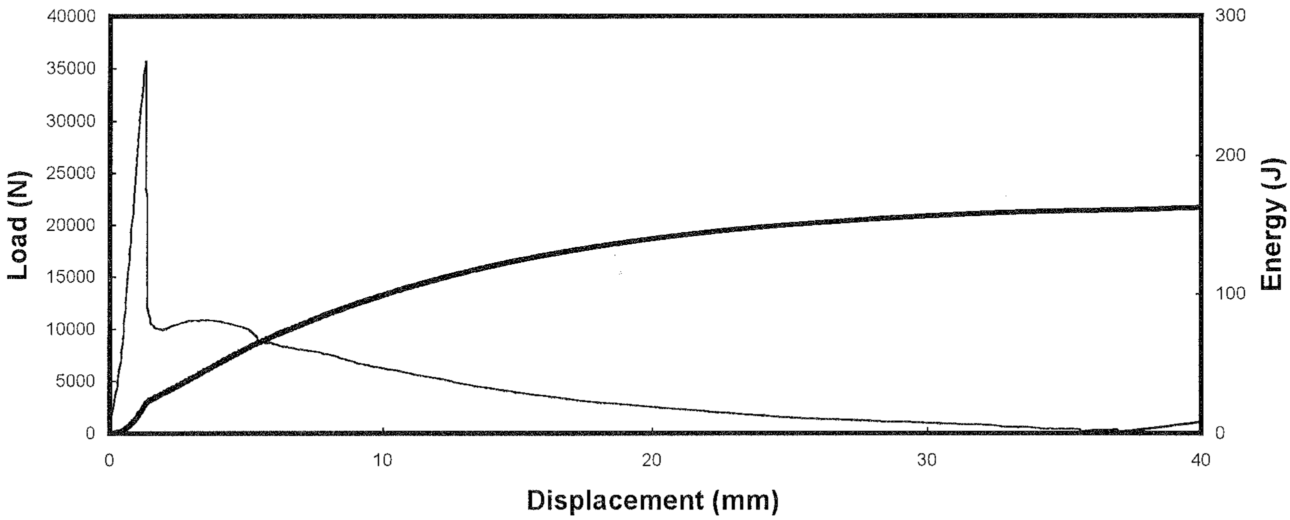
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V4-D07

Set: V4 Panel Set **Age:** 56 days **Date:** 1/29/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
806	9	82
800	10	81
802	23	80
	12	80
	18	79
mean: 802.7	8	76
	18	76
	13	76
	14	80
	17	80
	x: 14.2	79.0
	cov: 33.5	2.8

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

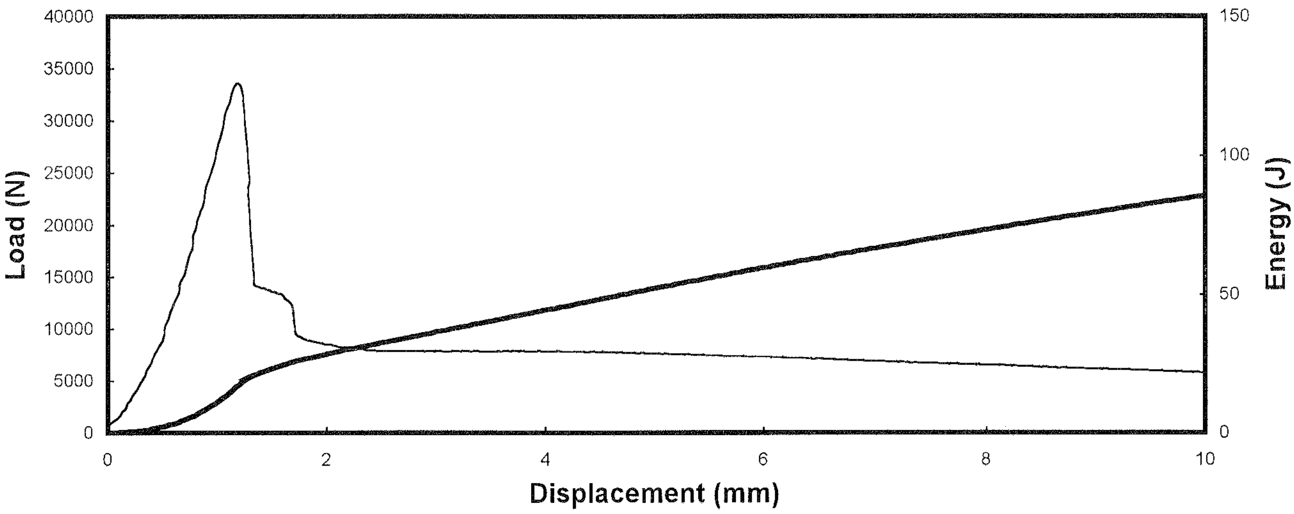
Parameter	Raw Results	Corrected
Peak Load (N)	**35667** N	**32040** N
Energy at 5 mm	**60** J	**54** J
Energy at 10 mm	**99** J	**90** J
Energy at 20 mm	**140** J	**127** J
Energy at 40 mm	**161** J	**148** J

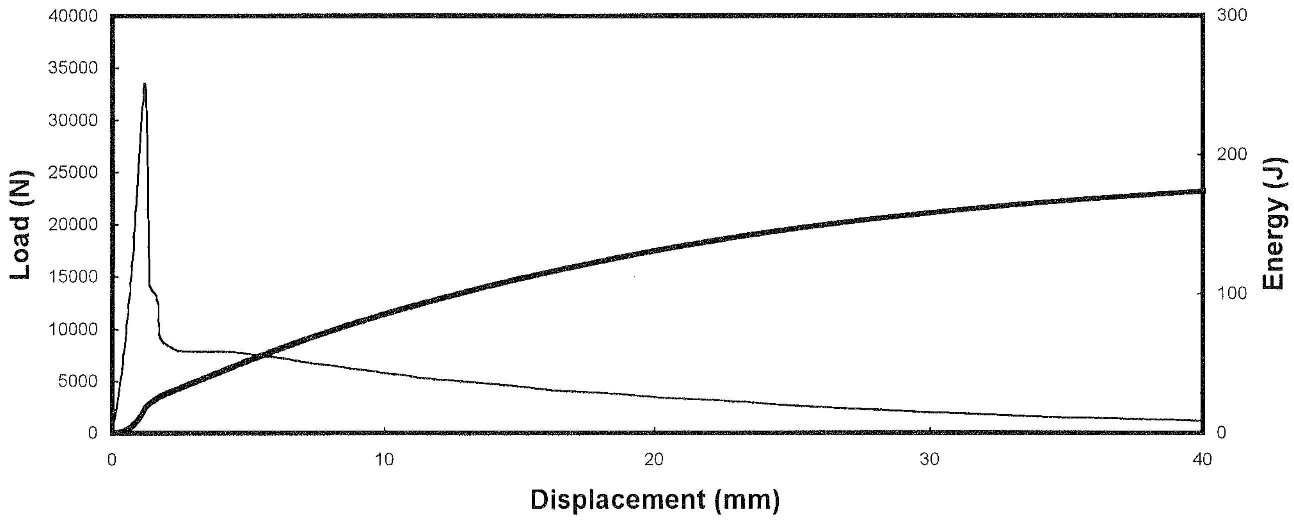
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V4-D08

Set: V4 Panel Set **Age:** 56 days **Date:** 1/29/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
800	12	78
803	9	78
806	16	78
	18	78
	19	79
mean: 803.0	22	77
	14	76
	10	76
	14	77
	18	76
	x: 15.2	77.3
	cov: 27.4	1.4

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

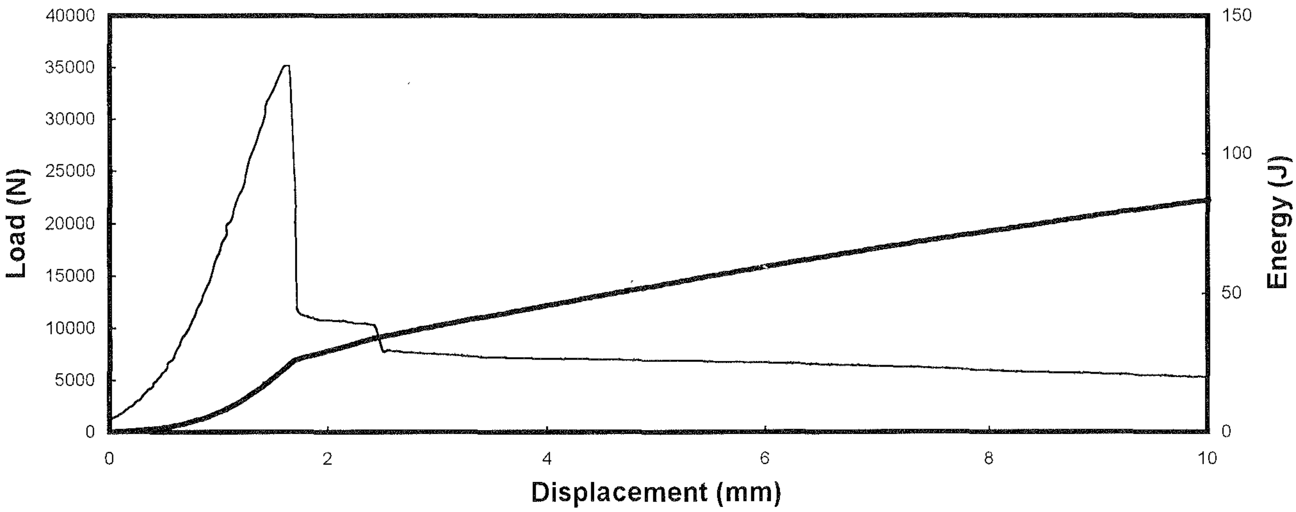
Parameter	Raw Results	Corrected
Peak Load (N)	33566 N	31480 N
Energy at 5 mm	52 J	49 J
Energy at 10 mm	85 J	80 J
Energy at 20 mm	131 J	124 J
Energy at 40 mm	173 J	165 J

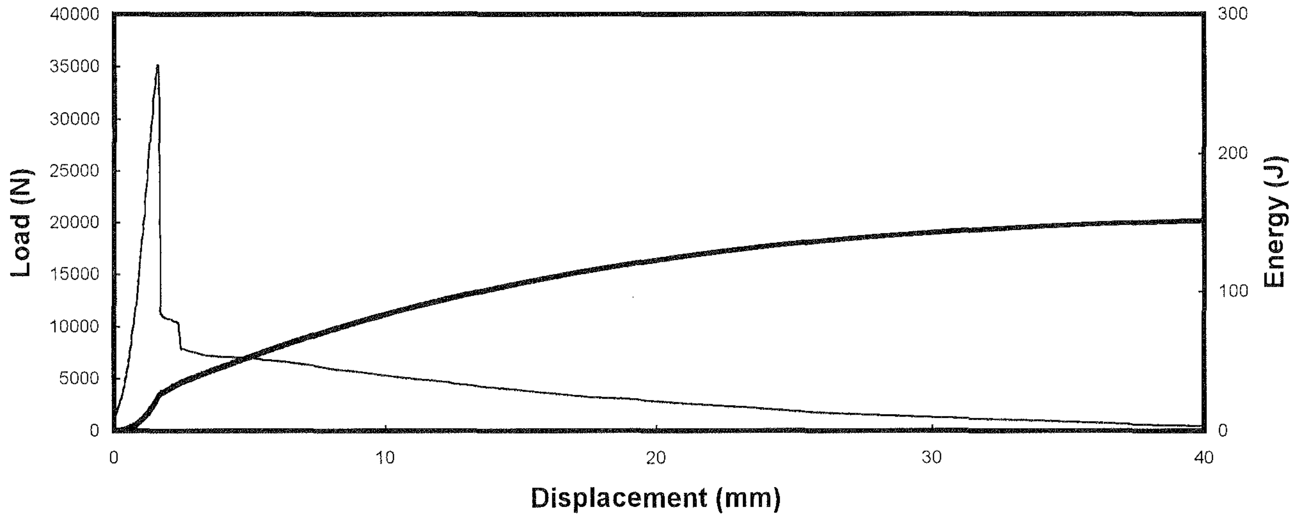
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V4-D09

Set: V4 Panel Set **Age:** 56 days **Date:** 1/30/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
803	17	80
804	16	81
804	16	80
	15	81
	18	81
mean: 803.7	21	75
	13	79
	17	76
	14	75
	13	76
x:	16	78.4
cov:	15.3	3.3

Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

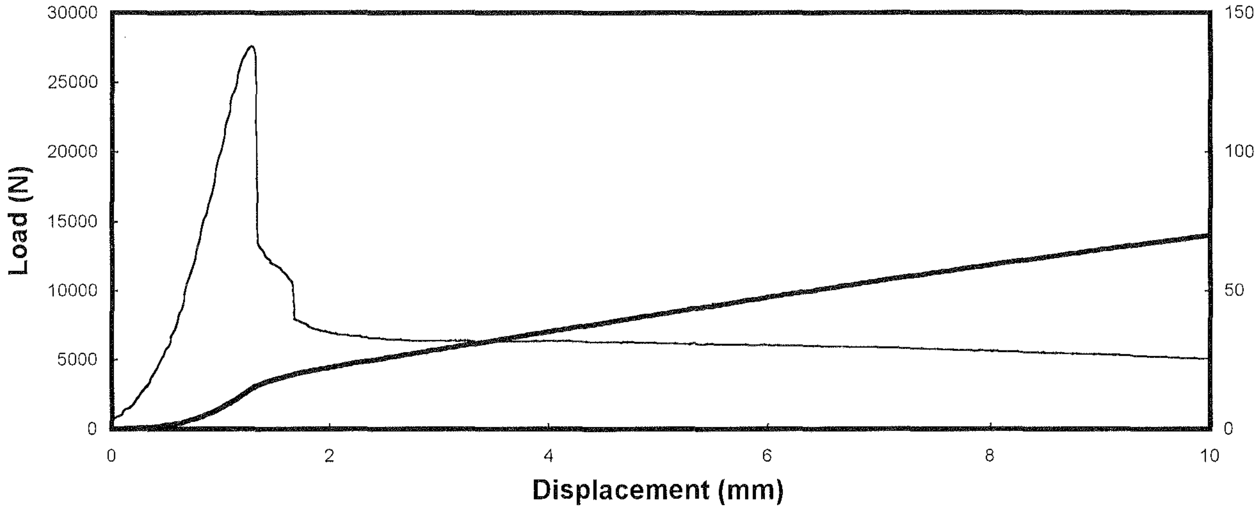
Parameter	Raw Results	Corrected
Peak Load (N)	**35185** N	**32052** N
Energy at 5 mm	**53** J	**48** J
Energy at 10 mm	**83** J	**76** J
Energy at 20 mm	**123** J	**113** J
Energy at 40 mm	**151** J	**141** J

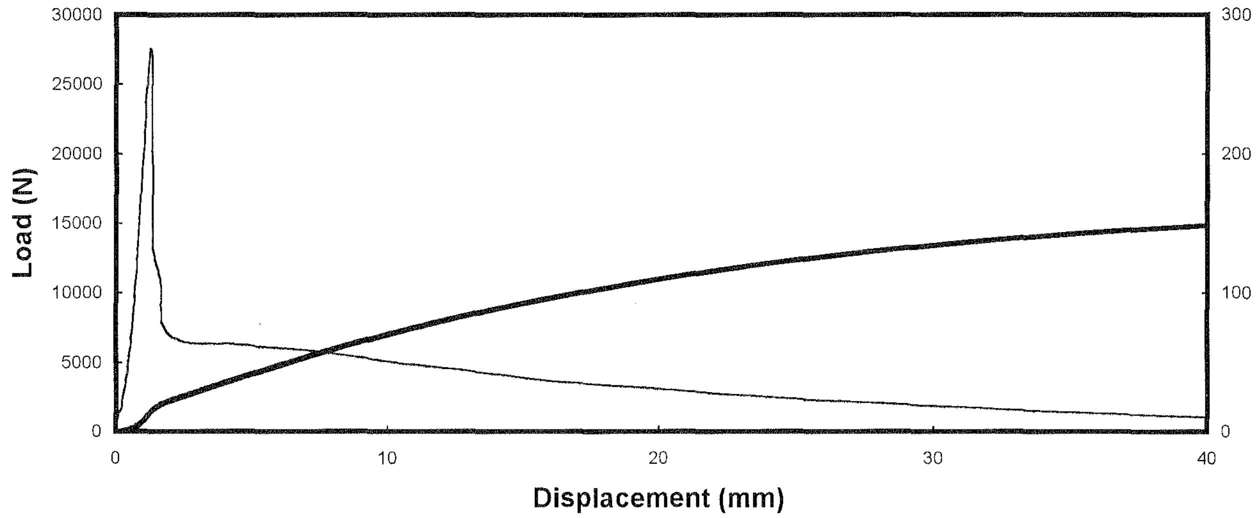
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V4-D10

Set: V4 Panel Set **Age:** 56 days **Date:** 1/30/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
800	15	71
801	8	71
804	12	71
	16	70
	28	71
mean: 801.7	12	74
	13	72
	17	78
	14	74
	9	77
	x: 14.4	72.9
	cov: 38.6	3.8

Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

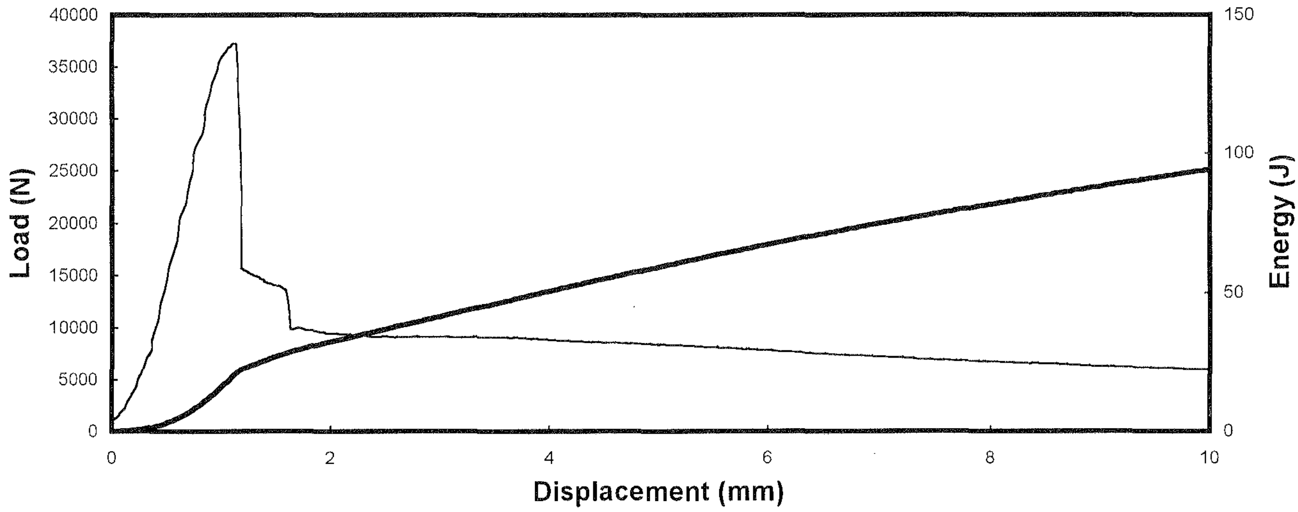
Parameter	Raw Results	Corrected
Peak Load (N)	**27605** N	**29158** N
Energy at 5 mm	**41** J	**43** J
Energy at 10 mm	**70** J	**74** J
Energy at 20 mm	**110** J	**115** J
Energy at 40 mm	**148** J	**154** J

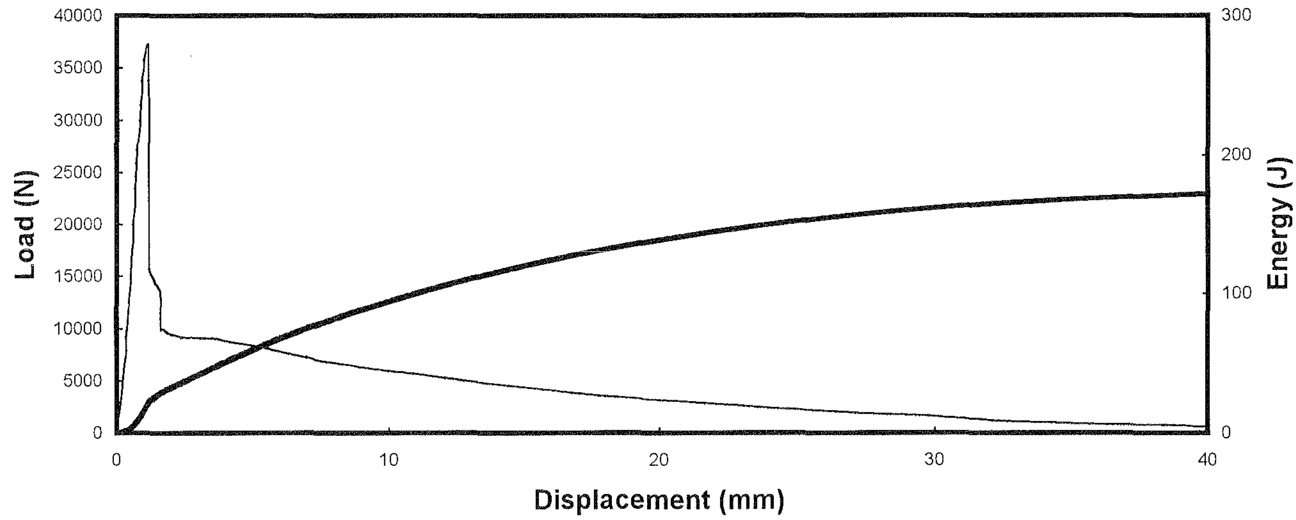
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V4-D11

Set: V4 Panel Set **Age:** 56 days **Date:** 1/30/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
804	17	80
802	10	80
806	10	81
	5	80
	10	81
mean: 804.0	9	76
	9	78
	24	77
	15	74
	13	75
	x: 12.2	78.2
	cov: 43.9	3.3

Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

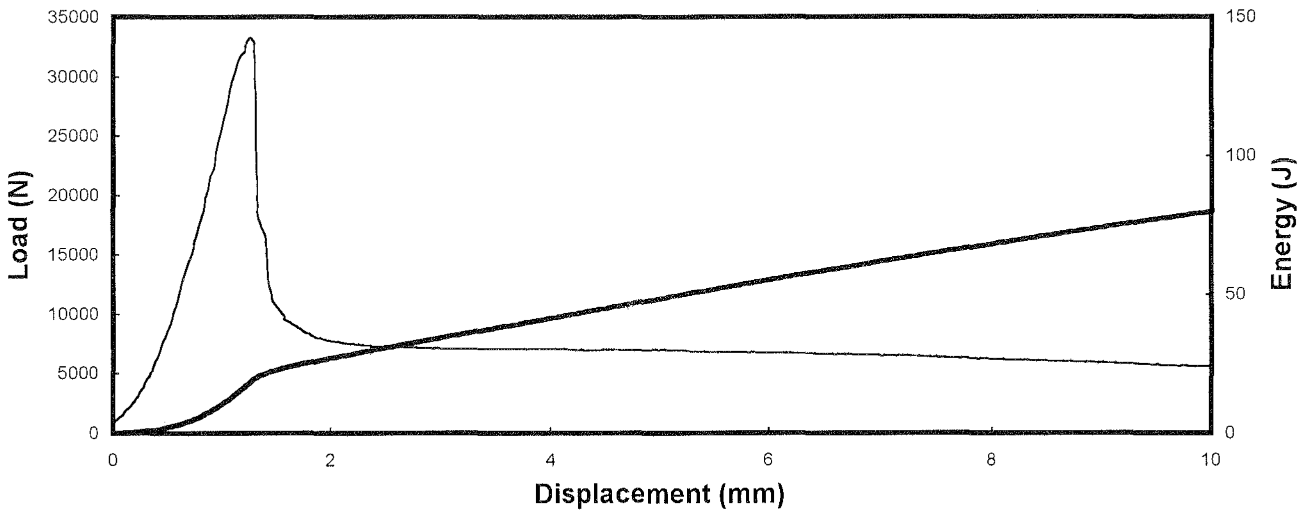
Parameter	Raw Results	Corrected
Peak Load (N)	37278 N	34119 N
Energy at 5 mm	59 J	54 J
Energy at 10 mm	94 J	87 J
Energy at 20 mm	138 J	128 J
Energy at 40 mm	172 J	160 J

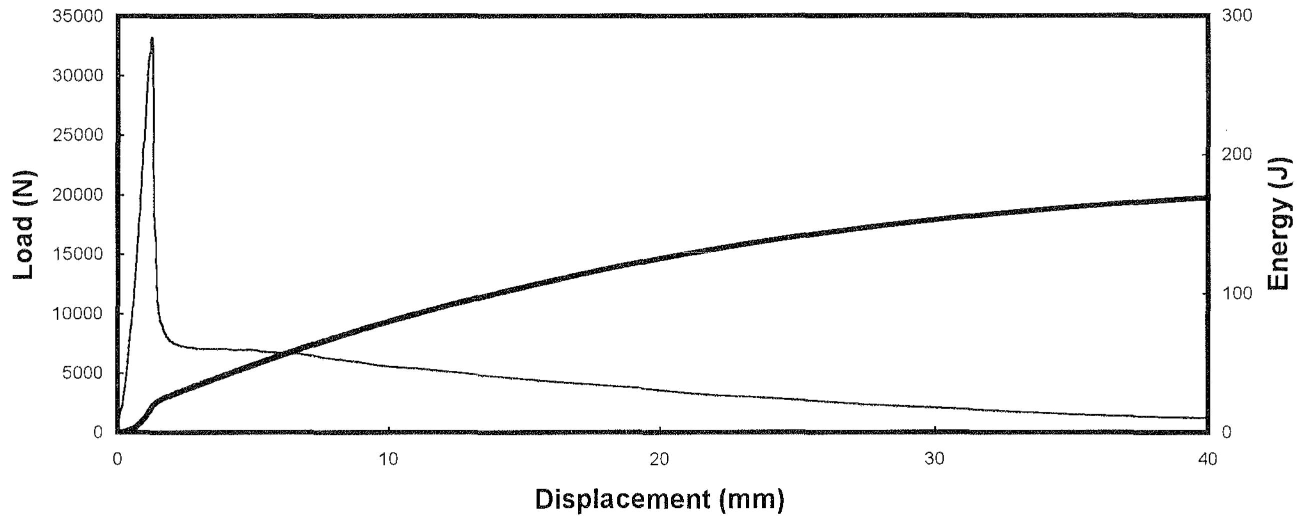
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result | **Specimen ID:** V4-D12

Set: V4 Panel Set | **Age:** 56 days **Date:** 1/30/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
806	10	80
795	11	80
807	9	80
	12	81
	20	80
mean: 802.7	14	75
	8	75
	11	74
	19	77
	15	76
	x: 12.9	77.8
	cov: 31.5	3.4

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

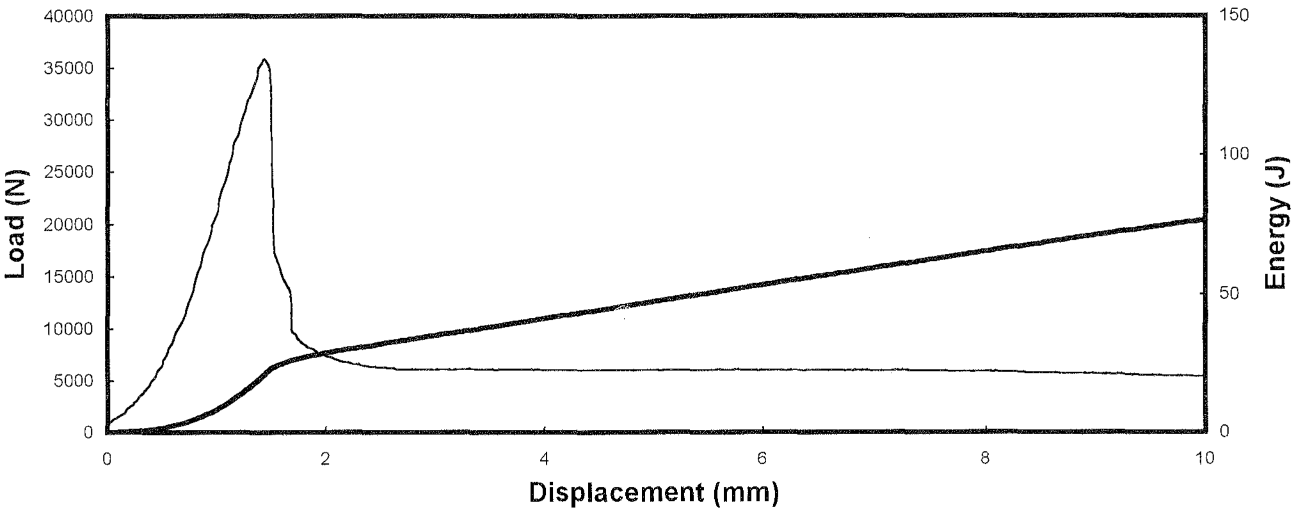
Parameter	Raw Results	Corrected
Peak Load (N)	33264 N	30810 N
Energy at 5 mm	48 J	45 J
Energy at 10 mm	80 J	74 J
Energy at 20 mm	125 J	117 J
Energy at 40 mm	169 J	159 J

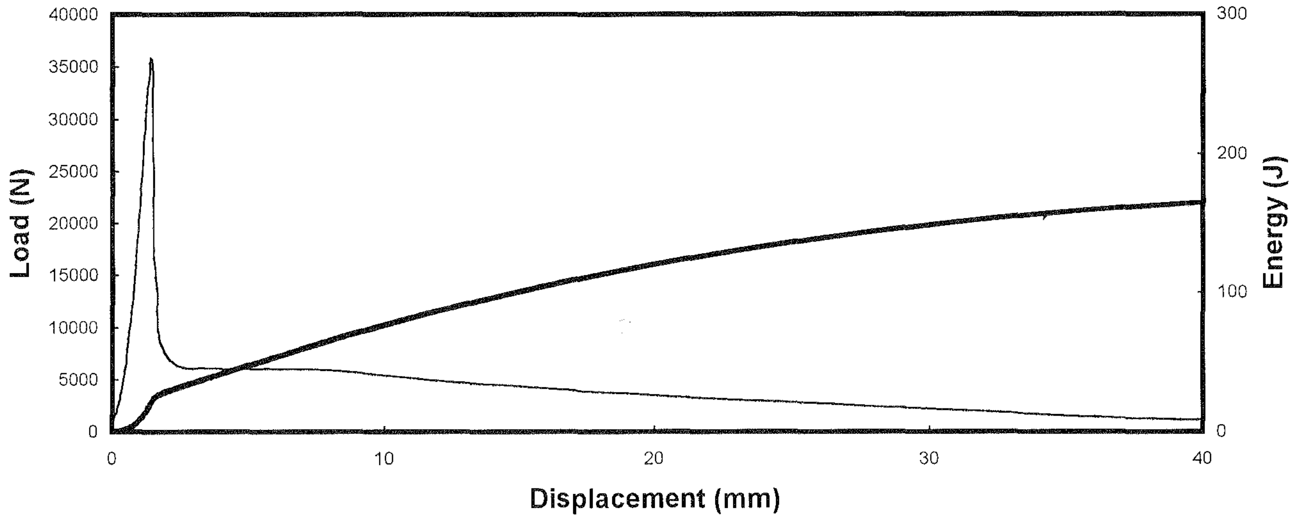
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V4-D13

Set: V4 Panel Set **Age:** 56 days **Date:** 1/30/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
799	13	81
796	18	81
797	14	79
	23	81
	11	81
mean: 797.3	13	75
Diameter was measured in the plane of the upper side of the specimen. Thickness was measured five times near the centre and five times near the edge of the specimen.	16	75
	10	80
	8	77
	9	78
x:	13.5	78.8
cov:	33.7	3.1

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	**35883** N	**32614** N
Energy at 5 mm	**47** J	**43** J
Energy at 10 mm	**76** J	**70** J
Energy at 20 mm	**120** J	**110** J
Energy at 40 mm	**164** J	**153** J

Performance corrections carried out according to Bernard and Pircher (2000)

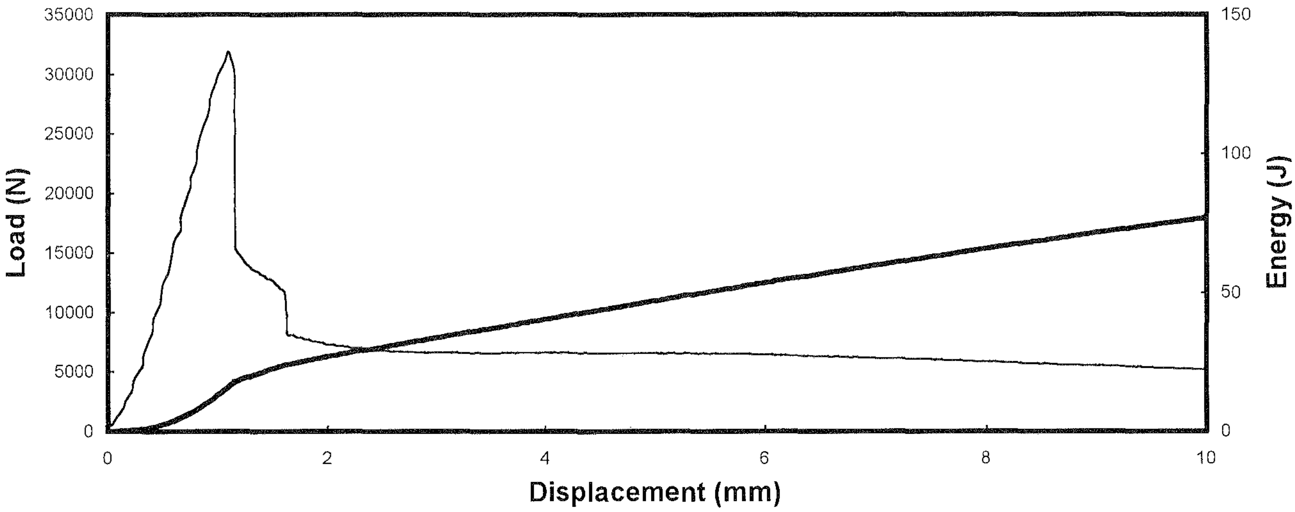
University of Western Sydney
School of Engineering and Design

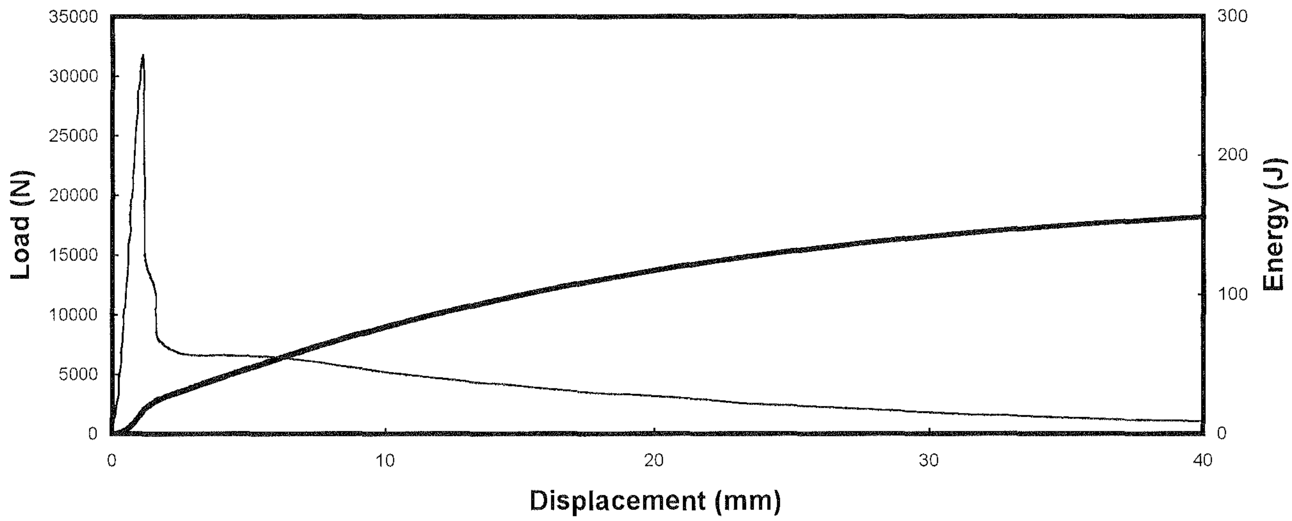
Round Determinate Panel Test Result

Specimen ID: V4-D14

Set: V4 Panel Set

Age: 56 days **Date:** 1/30/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
802	11	77
804	12	77
808	7	76
	10	77
	16	76
mean: 804.7	11	72
	13	76
	19	75
	19	75
	6	77
	x: 12.4	75.8
	cov: 36.1	2.0

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

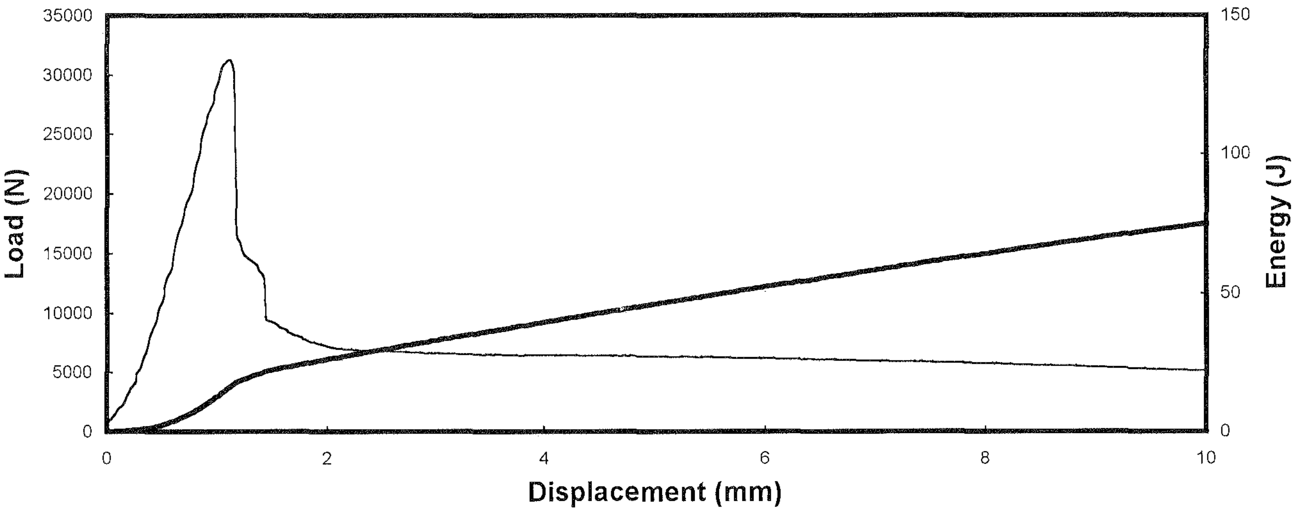
Parameter	Raw Results	Corrected
Peak Load (N)	31903 N	31052 N
Energy at 5 mm	47 J	46 J
Energy at 10 mm	77 J	75 J
Energy at 20 mm	117 J	114 J
Energy at 40 mm	155 J	152 J

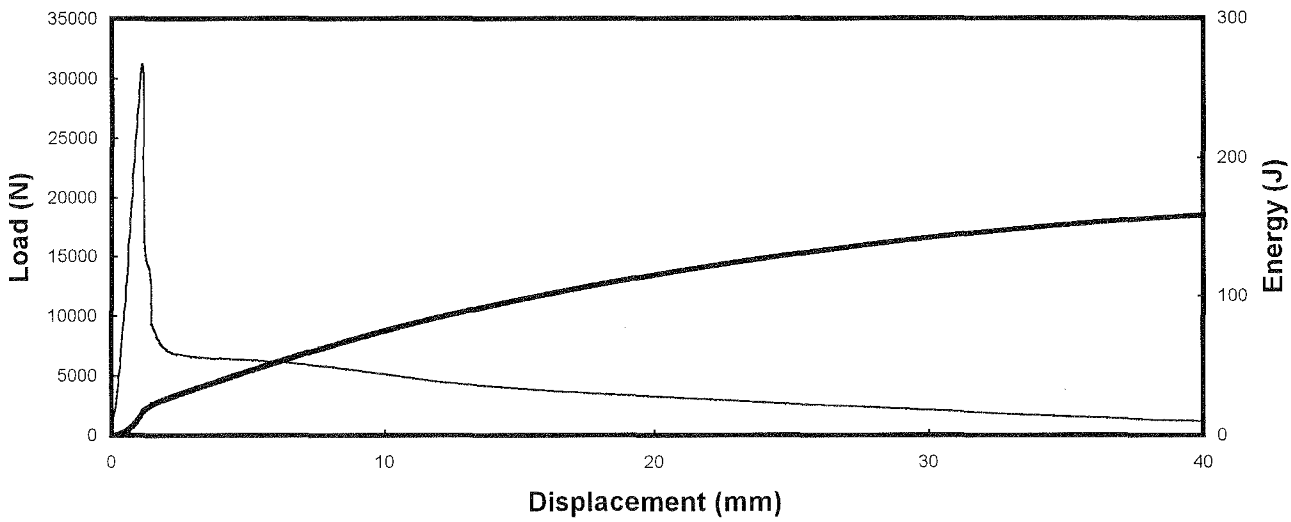
Performance corrections carried out according to Bernard and Pircher (2000)

University of Western Sydney
School of Engineering and Design

Round Determinate Panel Test Result **Specimen ID:** V4-D15

Set: V4 Panel Set **Age:** 56 days **Date:** 1/30/01





Specimen Dimensions

Diameter (mm)	Fibres	Thickness (mm)
804	9	77
800	11	77
805	13	76
	23	78
	13	77
mean: 803.0	15	75
	14	74
	14	77
	6	75
	14	74
	x: 13.2	76.0
	cov: 33.5	1.9

Diameter was measured in the plane of the upper side of the specimen.
Thickness was measured five times near the centre and five times near the edge of the specimen.

Comments

Base of specimen was perfectly seated with the centre located immediately below the loading ram. Surface and edges were smooth and well trowelled, thickness was even and close to specification.
Specimen failed in flexure with three primary radial cracks.

Parameter	Raw Results	Corrected
Peak Load (N)	31283 N	30352 N
Energy at 5 mm	46 J	44 J
Energy at 10 mm	75 J	73 J
Energy at 20 mm	115 J	112 J
Energy at 40 mm	158 J	155 J

Performance corrections carried out according to Bernard and Pircher (2000)

3. CONFERENCE PAPERS

Tran, V.N.G., Beasley A.J. and Bernard E.S., " Application of Yield Line Theory to Round Determinate Panels", International Conference on Engineering Developments in Shotcrete, April 2-4, 2001a, Hobart, Tasmania.

Tran, V.N.G., Beasley A.J. and Bernard E.S., "Monte Carlo Analysis for Crack Modelling in Fibre Reinforced Shotcrete Panels, ICCMC/IBST 2001, International Conference on Advanced Technologies in Design, Construction and Maintenance of Concrete Structures, March 28-29, 2001b, Hanoi, Vietnam.

Application of Yield Line Theory to Round Determinate Panels

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ABSTRACT: The Round Determinate panel test has been found to provide reliable and economical post-crack performance assessment for Fibre Reinforced Concrete (FRC) and Shotcrete (FRS). However, it suffers the problem that performance parameters obtained from this test are difficult to relate to the in situ behaviour of FRS. This investigation has sought to improve understanding about the behaviour of FRS in structures by examining the relationship between post-crack behaviour in beams and corresponding performance in Round Determinate panels. Several types of FRS exhibiting post-crack strain softening have been studied using Yield Line theory to predict the load-deflection response of round determinate panels based on moment-crack rotation relationships developed from tests on beams.

1 INTRODUCTION

Post-crack performance assessment for Fibre Reinforced Concrete (FRC) and Shotcrete (FRS) has been conducted using a variety of tests in recent years. The majority of these have involved beams (eg. JSCE 1984, EFNARC 1996, ASTM 1997), although panel-based procedures such as the EFNARC panel test (EFNARC 1996) and Round Determinate panel test (Bernard and Pircher 2000) also exist. Issues that require consideration when selecting the most appropriate test to use for performance assessment purposes include the reliability of results, the cost of testing, and whether the sample is truly representative of the *in situ* concrete. In all of these respects, the Round Determinate panel has been shown to be highly effective (Bernard 1998a).

Despite these advantages, the Round Determinate panel test suffers the disadvantage that the results are difficult to relate directly to the behaviour of FRS and FRC in structures such as tunnel linings and floors. While it is intuitively obvious that the load to cause first crack of a panel is related to the Modulus of Rupture, the mechanism by which the latter can be deduced from the former is not immediately obvious. The situation with respect to post-crack performance is even less clear. An investigation was therefore instigated to develop a theoretical basis for interpreting the results of Round Determinate panel tests so that they can be used to calculate behaviour in structures such as FRS tunnel linings. The study has focussed on the relationship between the performance of FRS beams and the corresponding behaviour of Round Determinate panels.

1.1 *Yield Line Theory*

In the design of concrete structures, engineers consider structural behaviour both prior to and after cracking of the concrete matrix. The load to cause cracking is therefore important. If conventional steel reinforcement is employed, the load to cause first yield of the steel also plays an important role in behaviour. Yield Line theory (Johansen 1972) has proven to be a simple and effective means of calculating the load to cause yielding of steel bars in conventionally reinforced concrete structures (Jones and Wood 1967) and first crack in fibre reinforced concrete floors (Concrete Society 1994). However, rational application of this theory to materials that display post-crack strain softening has been limited to date, and only a few examples exist in which post-crack behaviour in FRC has been modelled using Yield Line theory (Holmgren 1993).

Yield Line theory is widely used for moment redistribution and for the determination of collapse loads in suspended concrete slabs (Warner et al. 1998). However, design rules incorporating this method of analysis are qualified by the requirement that slabs be under-reinforced (eg. AS3600 1997). This is because collapse loads calculated on the basis of Yield Line theory are not valid at large deflections unless the moment capacity of elements within the slab display quasi-elastic perfectly plastic behaviour

(Johansen 1972). Slabs that are over-reinforced exhibit strain softening at low to moderate levels of deformation. Despite this, the determination of load capacity using Yield Line theory is not strictly limited to elastic perfectly plastic materials since this theory is based on the absorption of energy by deforming components of a chosen collapse mechanism. If the moment capacity of a component within a mechanism is altered, the work done in resisting external load changes and the load capacity will similarly change. This feature is the key to applying Yield Line theory in a step-wise analysis of strain softening materials.

In the present investigation, the Round Determinate panel has been considered a simple structure for which it is required to determine the load to cause first crack and post-crack behaviour. When a point load is introduced at the centre of a laboratory specimen, flexural stresses are developed throughout the panel. Based on elastic plate theory (Timoshenko and Woinowsky-Krieger 1959), the maximum tensile stress in an uncracked panel is predicted to occur on the opposite face along three radial lines between the supporting pivots (see Figure 1, from Bernard and Pircher 2000). As the load is increased, the tensile strength of the concrete matrix is eventually exceeded and a crack forms at the centre. This bifurcates and runs to the edges along the lines of maximum tensile stress to form a symmetric arrangement of three radial cracks. If the out-of-plane moment capacity of the material comprising the panel is truly elastic-perfectly plastic, the load resistance will be maintained as the deflection is increased. However, as the cracks widen they ultimately separate at the centre as a result of geometric constraints. No material will continue to support a moment across a discontinuity, so the load resistance will ultimately drop at severe deflections.

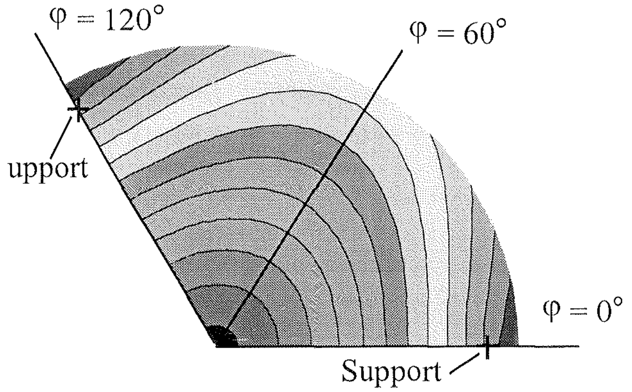

Figure 1. Radial stress distribution in a Round Determinate panel according to elastic plate theory (Bernard and Pircher 2000).

Consideration of experimentally observed collapse behaviour in Round Determinate panels suggests many similarities to the premises upon which Yield Line theory is based. To understand the similarities, it is necessary to examine the assumptions made in undertaking a Yield Line analysis. These include, that:

1. Each yield line (ie. crack) is a straight line. In reality, cracks are jagged and seldom straight.
2. The individual parts of a panel between the yield lines are regarded as plane. In real structures, quasi-elastic deformations arise from flexural, membrane, shear, and torsional stresses.
3. The deformation that occurs at each yield line consists of a relative rotation of the two adjoining parts of the panel about axes whose location depends upon the placement of supports.
4. Yield lines are taken to occur simultaneously. In reality, cracks propagate from the centre opposite face to the edges in succession.

To analyse a new structure for which the collapse mechanism is unknown, the following steps are undertaken as part of a Yield Line analysis:

1. A possible yield line pattern is adopted.
2. The ultimate moment capacity m per unit length is determined for the various yield lines.
3. The collapse load P corresponding to the assumed yield line pattern is calculated by consideration of structural equilibrium. This calculation can be achieved by the use of static or virtual work principles.
4. If necessary, the dimensions of the particular failure pattern are adjusted to minimise P.
5. If a different yield line pattern is possible, this pattern is assumed and steps 2 to 4 are repeated until a minimum value of P is found.

Central to this procedure is the virtual work theorem which states that the external work U_{ext} and the internal work U_{int} in a mechanism must be equal to maintain structural equilibrium. The external work is the summation of the products of applied (external) forces and their conjugate displacements that arise within the virtual displacement system. The internal work is the summation of the products of the internal stress resultants and their conjugate strains. In a Round Determinate panel test, the external force is the point load, P, applied at the centre of the panel, and its conjugate displacement is the deflection at the centre, δ. The internal stress resultants are the moments of resistance at each yield line, m, and their conjugate strains are the corresponding crack rotation angles.

The predicted load capacity of a structure depends on the pattern of yield lines chosen for analysis. According to Johansen (1972), the pattern that results in the lowest estimate of the equilibrium load will govern behaviour. Unfortunately, no method exists for predicting this pattern. Instead, it must be determined by trial and error, or by educated guesses. Not all patterns of yield lines are admissible. In the selection of a yield line pattern the following conditions must be satisfied:

1. A yield line between two parts of a panel must pass through the point of intersection of their axes of rotation (fold lines).
2. Each yield line pattern is determined by the axes of rotation of the various parts of the panel and the ratios between the rotations.
3. A line support must be an axis of rotation for a panel segment.
4. A point support must be on an axis of rotation.
5. A negative yield line must form at a fixed support.

For the case of a Round Determinate panel, several patterns of yield lines are possible and have been observed in laboratory tests. The two most common patterns are analysed as follows. The less common consists of a single diametral crack through the centre resulting in a beam-like failure of the panel. The more common consists of three radial cracks running from the centre to the free edges of the panel between the three pivot supports.

For the diametral pattern of yield lines (shown in Figure 2), the external and internal energies are expressed (Bernard and Pircher 2000)

$$U_{ext} = P\delta \tag{1}$$

and

$$U_{int} = 2R\theta m \tag{2}$$

where R is the radius of the panel, θ is the rotation at the yield line, and m is the moment of resistance per unit length of yield line. The rotation at the yield line is found as

$$\theta = \theta' + \theta'' \tag{3}$$

where

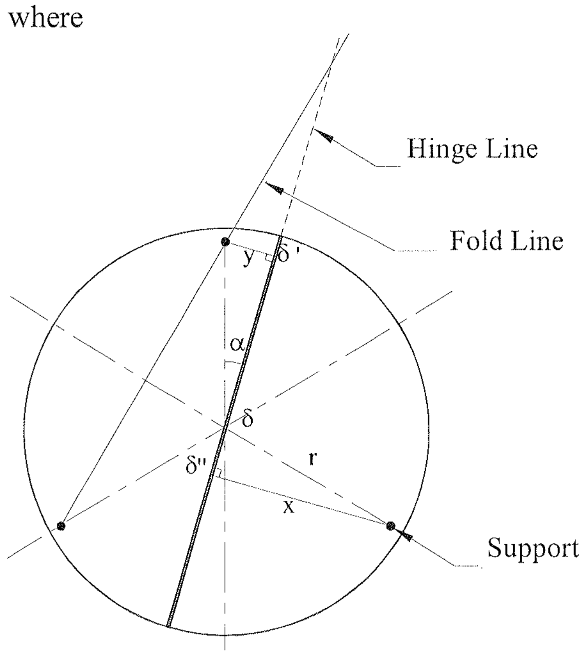

Figure 2. Diametral yield line pattern for Round Determinate panels.

$$\theta' = \frac{\delta'}{x} = \delta\frac{(1 - 2\cos\alpha\sin(\pi/6 - \alpha))}{r\sin\alpha} \tag{4}$$

and

$$\theta'' = \frac{\delta''}{y} = \delta\frac{(1 + 2\sin^2(\pi/6 - \alpha))}{r\cos(\pi/6 - \alpha)} \tag{5}$$

The failure load for this pattern is therefore

$$P = \frac{2Rm}{r}\left[\frac{1 - 2\cos\alpha\sin(\pi/6 - \alpha)}{\sin\alpha} + \frac{1 + 2\sin^2(\pi/6 - \alpha)}{\cos(\pi/6 - \alpha)}\right] \tag{6}$$

which is equal to a minimum value of

$$P = \frac{6mR}{r} \tag{7}$$

for $\alpha = \pi/6$. The pattern of three radial yield lines is analysed for the general case of three unequal angles between yield lines (see Figure 3) as follows. The external energy is expressed by Eqn. 1, but the internal energy is

$$U_{int} = R(m_1\theta_1 + m_2\theta_2 + m_3\theta_3) \tag{8}$$

where R is the radius of the panel, m_1, m_2, and m_3 are the moments of resistance per unit length along the three yield lines, and θ_1, θ_2, and θ_3 are the angles of rotation between the sets of planes. By the virtual work theorem, $U_{ext} = U_{int}$, hence

$$P = R(m_1\theta_1 + m_2\theta_2 + m_3\theta_3)/\delta \tag{9}$$

Since the uncracked portions of the panel are assumed to remain plane, the rotation angles at the yield lines are determined by their location and the geometry of the panel. The three angles of rotation are calculated below with reference to Figure 4, which shows a Round Determinate panel with three radial cracks arranged at arbitrary angles $\gamma_1, \gamma_2, \gamma_3$ with respect to the bisectors of the unsupported sides. Considering the yield line radiating to the lower-most corner (E), the distance from pivot K to the closest point on the yield line, B, is found as

$$h_{13} = r.\sin(\pi/3 + \gamma_1) \tag{10}$$

and the distance from pivot I to the closest point on the yield line, C, is found as

$$h_{12} = r.\sin(\pi/3 - \gamma_1) \qquad (11)$$

where r is the radius to the pivoted supports. The deflections at points B and C are found as

$$\delta_B = (z - x).\ \delta/z \qquad (12)$$

$$\delta_C = (z - y).\ \delta/z \qquad (13)$$

where x is the distance from the centre, A, to B,

$$x = r.\cos(\pi/3 + \gamma_1) \qquad (14)$$

y is the distance from A to C,

$$y = r.\cos(\pi/3 - \gamma_1) \qquad (15)$$

and z is the distance from A to E,

$$z = r.\cos(\pi/3 - \gamma_1) + h_{12}/\tan\alpha_2$$

$$= r.\sin(\alpha_2 + \pi/3 - \gamma_1)/\sin\alpha_2 \qquad (16)$$

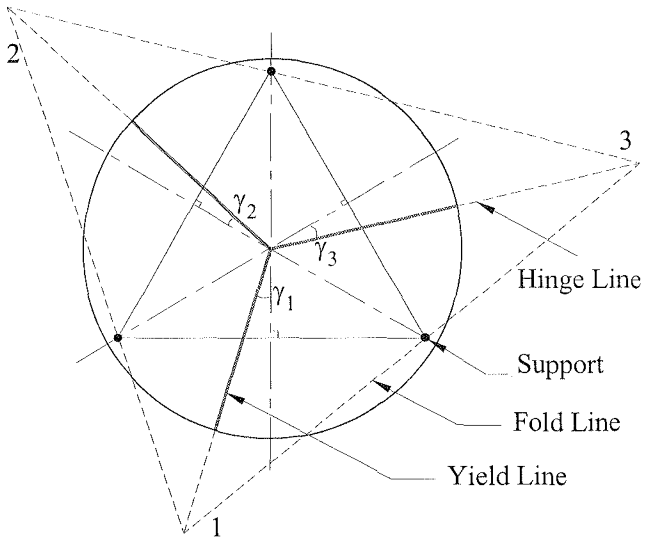

Figure 3. General pattern of three radial yield lines at unequal angles for a Round Determinate panel.

To find δ_B and δ_C it is firstly necessary to determine the relationship between the corner angles α_1, α_2, α_3, α_4, α_5, and α_6. Consideration of triangles *JUZ*, *AU3*, *AVZ* and *KV3* gives:

$$\xi - \alpha_5 = \gamma_3 - \pi/6 \qquad (17)$$

$$\phi + \alpha_6 = \gamma_3 + \pi/6 \qquad (18)$$

Similarly,

$$\phi - \alpha_1 = \gamma_1 - \pi/6 \qquad (19)$$

$$\nu + \alpha_2 = \gamma_1 + \pi/6 \qquad (20)$$

$$\nu - \alpha_3 = \gamma_2 - \pi/6 \qquad (21)$$

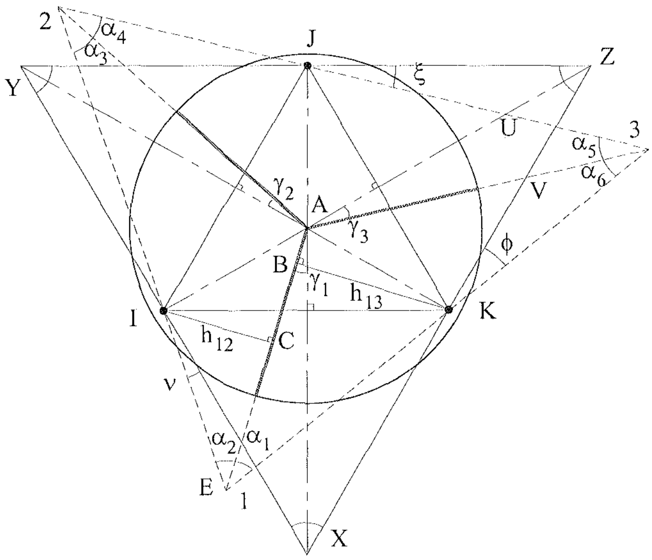

Figure 4. Detail of geometry for a general pattern of three radial yield lines at unequal angles for a Round Determinate panel. Note: ξ, ϕ, ν are the angles between the sides of the general triangle 123 and symmetric triangle XYZ.

$$\xi + \alpha_4 = \gamma_2 + \pi/6 \qquad (22)$$

From (17) to (22),

$$\alpha_1 + \alpha_6 - \gamma_3 + \gamma_1 = \pi/3 \qquad (23)$$

$$\alpha_2 + \alpha_3 - \gamma_1 + \gamma_2 = \pi/3 \qquad (24)$$

$$\alpha_4 + \alpha_5 - \gamma_2 + \gamma_3 = \pi/3 \qquad (25)$$

Based on the expressions listed above, it is possible to develop a system of equations to solve for the angle α_2, and subsequently find the remaining angles. Using this approach,

$$\alpha_2 = \operatorname{atan}\left[\frac{\cos(\gamma_1 + \frac{\pi}{6})}{-\sqrt{3}.\sin\gamma_1 + \dfrac{\cos(\gamma_1 - \frac{\pi}{6})}{A_1}}\right] \qquad (26)$$

where $A_1 = \tan(\frac{\pi}{3} - \gamma_1 + \gamma_3 - A_2)$

$$A_2 = \operatorname{atan}\left[\frac{\cos(\gamma_3 + \frac{\pi}{6})}{-\sqrt{3}.\sin\gamma_3 + \dfrac{\cos(\gamma_3 - \frac{\pi}{6})}{A_3}}\right]$$

$A_3 = \tan(\frac{\pi}{3} - \gamma_3 + \gamma_2 - A_4)$ and

$$A_4 = \text{atan}\left[\frac{\cos(\gamma_2 + \frac{\pi}{6})}{-\sqrt{3}.\sin\gamma_2 + \frac{\cos(\gamma_2 - \frac{\pi}{6})}{\tan(\frac{\pi}{3} - \gamma_2 + \gamma_1 - \alpha_2)}}\right]$$

Similarly,

$$\alpha_4 = \text{atan}\left[\frac{\cos(\gamma_2 + \frac{\pi}{6})}{-\sqrt{3}.\sin\gamma_2 + \frac{\cos(\gamma_2 - \frac{\pi}{6})}{B_1}}\right] \quad (27)$$

where $B_1 = \tan(\frac{\pi}{3} - \gamma_2 + \gamma_1 - B_2)$

$$B_2 = \text{atan}\left[\frac{\cos(\gamma_1 + \frac{\pi}{6})}{-\sqrt{3}.\sin\gamma_1 + \frac{\cos(\gamma_1 - \frac{\pi}{6})}{B_3}}\right]$$

$$B_3 = \tan(\frac{\pi}{3} - \gamma_1 + \gamma_3 - B_4)$$

$$B_4 = \text{atan}\left[\frac{\cos(\gamma_3 + \frac{\pi}{6})}{-\sqrt{3}.\sin\gamma_3 + \frac{\cos(\gamma_3 - \frac{\pi}{6})}{\tan(\frac{\pi}{3} - \gamma_3 + \gamma_2 - \alpha_4)}}\right]$$

and

$$\alpha_6 = \text{atan}\left[\frac{\cos(\gamma_3 + \frac{\pi}{6})}{-\sqrt{3}.\sin\gamma_3 + \frac{\cos(\gamma_3 - \frac{\pi}{6})}{C_1}}\right] \quad (28)$$

where $C_1 = \tan(\frac{\pi}{3} - \gamma_3 + \gamma_2 - C_2)$

$$C_4 = \text{atan}\left[\frac{\cos(\gamma_2 + \frac{\pi}{6})}{-\sqrt{3}.\sin\gamma_2 + \frac{\cos(\gamma_2 - \frac{\pi}{6})}{C_3}}\right]$$

$$C_3 = \tan(\frac{\pi}{3} - \gamma_2 + \gamma_1 - C_4)$$

$$C_4 = \text{atan}\left[\frac{\cos(\gamma_1 + \frac{\pi}{6})}{-\sqrt{3}.\sin\gamma_1 + \frac{\cos(\gamma_1 - \frac{\pi}{6})}{\tan(\frac{\pi}{3} - \gamma_1 + \gamma_3 - \alpha_6)}}\right]$$

The corner angles can be found for any γ_1, γ_2, and γ_3 by solving equations (26) to (28) through iteration. The rotation of yield line *AE* is then expressed as

$$\theta_1 = \text{atan}(\delta_C/h_{12}) + \text{atan}(\delta_B/h_{13}) \quad (29)$$

which can be re-arranged as

$$\theta_1 = \text{atan}(A\delta) + \text{atan}(B\delta) \quad (30)$$

where

$$A = \left[\frac{\sin(\alpha_2 + \frac{\pi}{3} - \gamma_1) - \cos(\frac{\pi}{3} - \gamma_1).\sin\alpha_2}{r.\sin(\frac{\pi}{3} - \gamma_1).\sin(\alpha_2 + \frac{\pi}{3} - \gamma_1)}\right] \quad (31)$$

$$B = \left[\frac{\sin(\alpha_2 + \frac{\pi}{3} - \gamma_1) - \cos(\frac{\pi}{3} + \gamma_1).\sin\alpha_2}{r.\sin(\frac{\pi}{3} + \gamma_1).\sin(\alpha_2 + \frac{\pi}{3} - \gamma_1)}\right] \quad (32)$$

Similarly, the rotations of the other two yield lines can be expressed as

$$\theta_2 = \text{atan}(C\delta) + \text{atan}(D\delta) \quad (33)$$

$$\theta_3 = \text{atan}(E\delta) + \text{atan}(F\delta) \quad (34)$$

where

$$C = \left[\frac{\sin(\alpha_4 + \frac{\pi}{3} - \gamma_2) - \cos(\frac{\pi}{3} - \gamma_2).\sin\alpha_4}{r.\sin(\frac{\pi}{3} - \gamma_2).\sin(\alpha_4 + \frac{\pi}{3} - \gamma_2)}\right] \quad (35)$$

$$D = \left[\frac{\sin(\alpha_4 + \frac{\pi}{3} - \gamma_2) - \cos(\frac{\pi}{3} + \gamma_2).\sin\alpha_4}{r.\sin(\frac{\pi}{3} + \gamma_2).\sin(\alpha_4 + \frac{\pi}{3} - \gamma_2)} \right] \quad (36)$$

$$E = \left[\frac{\sin(\alpha_6 + \frac{\pi}{3} - \gamma_3) - \cos(\frac{\pi}{3} - \gamma_3).\sin\alpha_6}{r.\sin(\frac{\pi}{3} - \gamma_3).\sin(\alpha_6 + \frac{\pi}{3} - \gamma_3)} \right] \quad (37)$$

$$F = \left[\frac{\sin(\alpha_6 + \frac{\pi}{3} - \gamma_3) - \cos(\frac{\pi}{3} + \gamma_3).\sin\alpha_6}{r.\sin(\frac{\pi}{3} + \gamma_3).\sin(\alpha_6 + \frac{\pi}{3} - \gamma_3)} \right] \quad (38)$$

The load to cause first crack of the concrete matrix can be found when the deflection tends to zero because elastic deformation prior to cracking is ignored. Therefore, from Eqn. 9,

$$P_{Crack} = \lim_{\delta \to 0} P = R\left[m_1 \lim_{\delta \to 0} \frac{\theta_1}{\delta} + m_2 \lim_{\delta \to 0} \frac{\theta_2}{\delta} + m_3 \lim_{\delta \to 0} \frac{\theta_3}{\delta} \right] \quad (39)$$

Applying L'Hopital's Rule,

$$\lim_{\delta \to 0} \frac{\theta_1}{\delta} = \lim_{\delta \to 0} \frac{[a\tan(A\delta) + a\tan(B\delta)]}{\delta} = A + B \quad (40)$$

Similarly,

$$\lim_{\delta \to 0} \frac{\theta_2}{\delta} = C + D \quad \text{and} \quad \lim_{\delta \to 0} \frac{\theta_3}{\delta} = E + F \quad (41)$$

Thus,

$$P_{Crack} = R(m_1(A+B) + m_2(C+D) + m_3(E+F)) \quad (42)$$

For the symmetric case in which all included angles between yield lines equal 120° (ie. all midpoint angles γ equal zero), $m_1 = m_2 = m_3 = m$ and

$$A = B = C = D = E = F = \frac{\sqrt{3}}{2r} \quad (43)$$

Thus,

$$P_{Crack} = 3\sqrt{3}m\frac{R}{r} \quad (44)$$

This expression is the same as Eqn 12 in Bernard (1998b) which was obtained by a simplified analysis of the symmetric case. The magnitude of this estimate of P_{crack} is 13 per cent lower than the value given in Eqn. 7 for the diametral mode of failure, so the symmetric mode of failure will theoretically govern behaviour.

The analysis described above is applicable to any collapse mechanism for which the moment resistance at each yield line is known. At the point of first crack of the concrete matrix, the moment resistance is the moment to cause first crack in beam elements representing the one-way bending capacity of the panel. Post-crack capacity can be determined by increasing the displacement at the centre of the panel and using the moment of resistance offered by beams at each corresponding crack rotation angle to find the load at equilibrium with these moments. The post-crack analysis must be performed in a step-wise manner to model the changing moment of resistance offered by each of the yield lines as the rotation angles increase.

1.2 *Energy Calculation*

The theory described above outlines the approach required to solve for geometric constraints upon yield line formation in a round determinate panel. However, there are two alternative approaches to the solution of the virtual work theorem. The difference them is related to the way the internal energy is calculated, as shown below.

1.2.1 *Standard Model*

In this model the moment of resistance at each yield line is taken to be constant between the onset of loading and the crack rotation angle under consideration, but the degree of resistance to deformation changes as the crack rotation angle increases. The internal energy is calculated for each yield line as

$$U_{int} = ml\theta \quad (45)$$

where m is taken to be the instantaneous moment capacity offered by a particular yield line of length l at a crack rotation angle of θ. This is represented graphically by the shaded area in Figure 5.

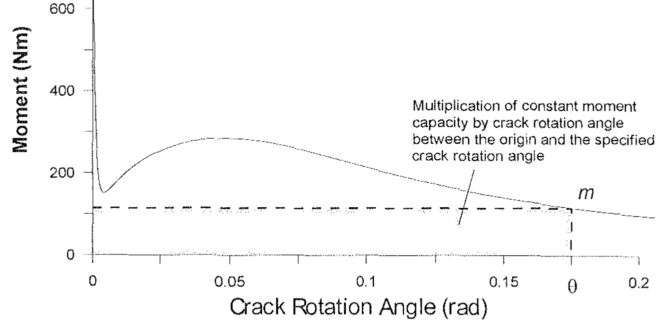

Figure 5. Standard approach to determination of moment-crack rotation relation between onset of cracking and a crack rotation angle of θ.

1.2.2 *Integration Model*

An alternative approach is to consider the variation in moment capacity at each yield line up to the level of deformation under consideration and incorporate this into the energy calculation expression. This is equivalent to

$$U_{int} = \int m(\theta) l \, d\theta \tag{46}$$

in which m is taken to vary as a function of θ as shown in Figure 6. The two approaches produce the same result for elastic perfectly plastic materials, but produce different results for other types of post-cracking behaviour.

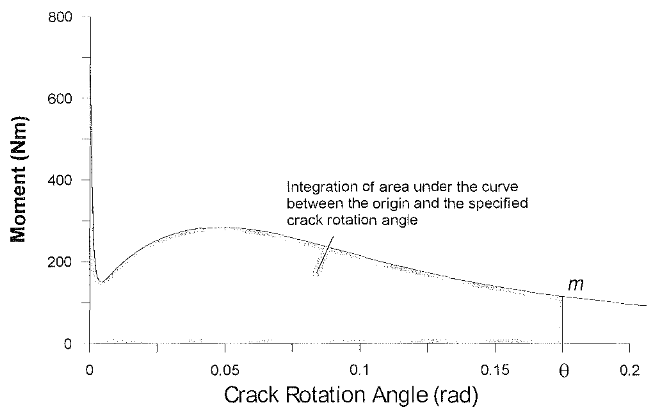

Figure 6. Integration of moment-crack rotation relation between onset of cracking and a crack rotation angle of θ.

1.3 *Numerical Analysis*

The theory outlined above was developed into a numerical program to carry out a step-wise analysis of post-crack behaviour in Round Determinate panels. For each increment of displacement at the centre, the rotation at each crack was calculated and used to find the moment of resistance based on a moment-crack rotation relationship derived from beams. The virtual work theorem was then used to solve for the load resistance using both the standard and integration approaches to internal energy calculation. The structure and operation of the program are described in Figure 7.

2 EXPERIMENTAL VALIDATION

Validation of the theory and numerical methods described above was carried out using data obtained from an experimental study by Bernard et al. (2000). This study involved tests on large numbers of Round Determinate panels and Centrally Loaded beams produced using identical materials. Four sets of specimens were produced using shotcrete reinforced with seven different types of fibre. Each set consisted of 20 beams and 20 panels in order to develop very reliable estimates of the characteristic behaviour. The mix design used by Bernard et al (2000) for the concrete is listed in Table 1, and the fibre types and dosages are listed in Table 2. Note that more than one type of fibre was used in some of the mixes to achieve certain post-crack characteristics.

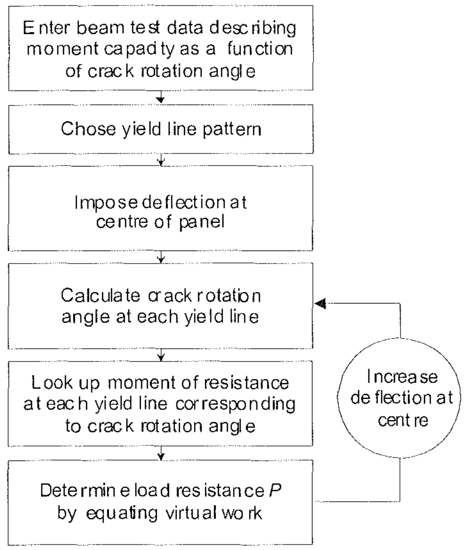

Figure 7. Structure and operation of numerical code for the estimation of post-crack behaviour using Yield Line theory.

Table 1. Mix design for FRC, all quantities in kg/m^3 unless otherwise indicated.

Ingredient	Sets 1-3	Set 4
Coarse agg. (5/7 mm)	640	640
Coarse sand (5 mm)	620	560
Fine sand (2 mm)	420	380
Cement (ASTM Type 1)	360	380
Fly ash	-	40
Silica Fume	40	40
Water reducer	1900 mL	1900 mL
Slump	65 mm	65 mm

Table 2. Fibre dosages (and source) used for each specimen set.

Set	Fibre type	Dosage (kg/m^3)
1	Novotex 0730 (Synthetic Ind.)	34
	256 EE (BHP Fibresteel)	27
2	50 mm HPP (Synthetic Ind.)	12
3	52 mm polyolefin (Dalhousie)	7.5
4	Dramix RC65/35 (Bekaert)	20
	Dramix BP80/35 (Bekaert)	15
	50 mm HPP (Synthetic Ind.)	3

2.1 *Beam testing*

Moment-crack rotation relationships were measured using the Centrally Loaded Beam test, developed by Bernard (1999). This test involves the imposition of a central point load on a saw-cut FRS beam and measurement of rotation at the crack as a function of the applied moment. In contrast to data produced using conventional third-point loaded beams (ASTM 1997, EFNARC 1996) this test results in data of direct structural relevance. The size of the specimen used is the same as that used in the EFNARC third-point beam test (75×125×550 mm, on a 450 mm span). The method used to measure and calculate the relationship between moment and crack rotation in these specimens is described in detail in Bernard et al. (2000).

2.2 *Panel testing*

In the Round Determinate panel test (Bernard and Pircher 2000) a central point load is imposed on a specimen measuring 75×800 mm diameter, supported on three radial points located on a 750 mm diameter. Specimens tested by Bernard et al (2000) were placed in a test fixture located within an Instron 8506 servo-hydraulic test machine and loaded in displacement-control up to 100 mm total central deflection.

3 RESULTS

The results of the experiments by Bernard et al. (2000) consisted of data representing the moment-crack rotation relationships for four sets of Centrally Loaded beams, and load-deflection histories for four corresponding sets of Round Determinate panels. An example of the results for specimen Set 3 are shown in Figures 8 and 9. The results for each set of nominally identical specimens have been super-imposed to illustrate the level of variability typical for the beams and panels. Note that the beams generally suffered a very abrupt drop in moment capacity immediately after cracking. This was particularly pronounced in the sets reinforced with polymer fibres.

A proprietary curve-fitting program called *Tablecurve 2-D* was used to perform a least-squares adjusted curve fit of 3667 linear and non-linear two dimensional expressions to each set of experimental data. This was carried out so that the beam results could be used as input to the numerical analysis. The panel test results were curve-fitted so that they could be compared to the results of the numerical analysis. The curve-fitted equations for specimen Set 3 are superimposed as dark lines in Figures 8 and 9. For each set of specimens, all 20 results were analysed simultaneously to arrive at the most suitable expression. The panel data used in these analyses was not corrected for thickness or diameter.

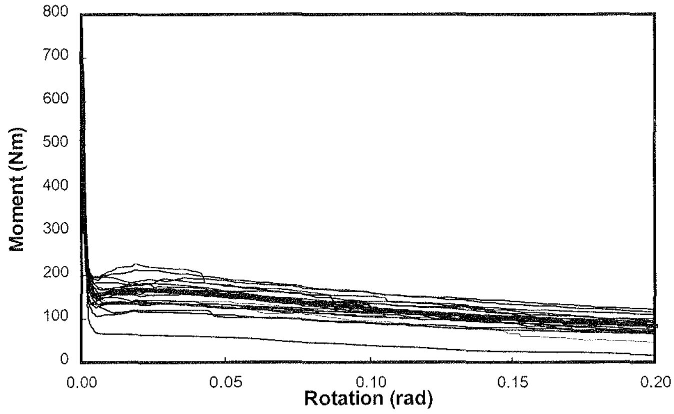

Figure 8. Moment-crack rotation data generated for Centrally Loaded beams from Set 3.

The expressions that resulted from curve-fitting the beam test data were used as input to the Yield Line analysis to produce estimates of post-crack behaviour in the panels. These have been compared to the experimental results from the panel tests in Figures 10 to 13 and in Table 3. In each of these figures, the dark line represents the curve-fitted expression for the results of 20 panel tests. The other two lines represent the results of numerical analysis based on moment-crack rotation data obtained from the beam tests. All the numerical analyses were performed for a symmetric arrangement of 3 radial yield lines and the pre-crack displacement has been subtracted from the record.

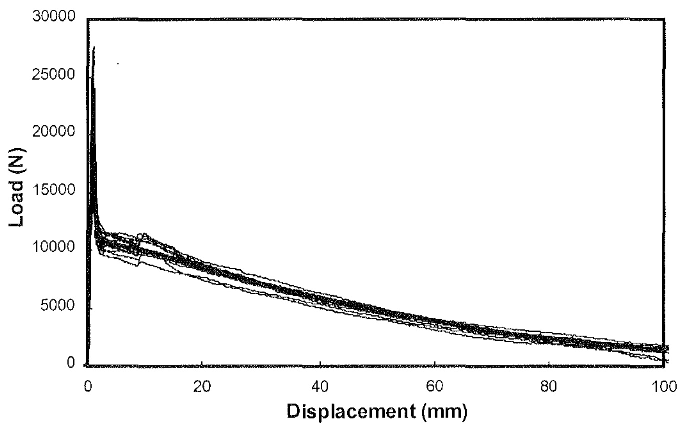

Figure 9. Load-displacement data generated for Round Determinate panels from Set 3.

Table 3. Comparison of experimental and theoretical results obtained by Yield Line analysis

Panel	Load to Cause First Crack (N)			Residual Load at 40 mm (N)				
Set	Experiment	Theory	Test/Theory	Experiment	Standard	Test/Standard	Integration	Test/Integration
1	33160	37263	0.890	1316	1358	0.969	7940	0.1710
2	23371	32165	0.727	4128	4745	0.870	10459	0.3947
3	28179	31828	0.885	5696	3860	1.476	7088	0.8036

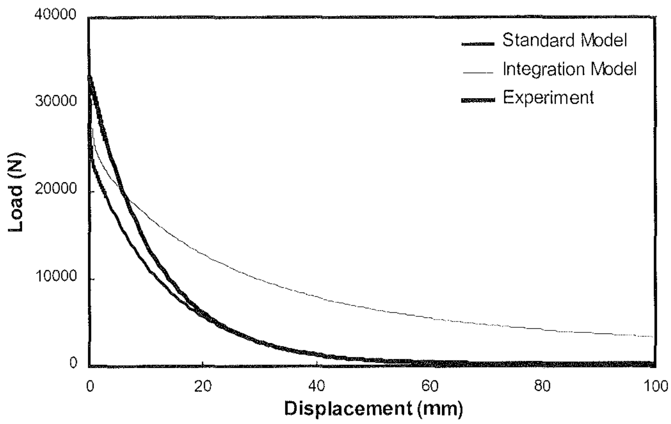

Figure 10. Load-displacement curves for Set 1 derived from experiments and Yield Line analysis.

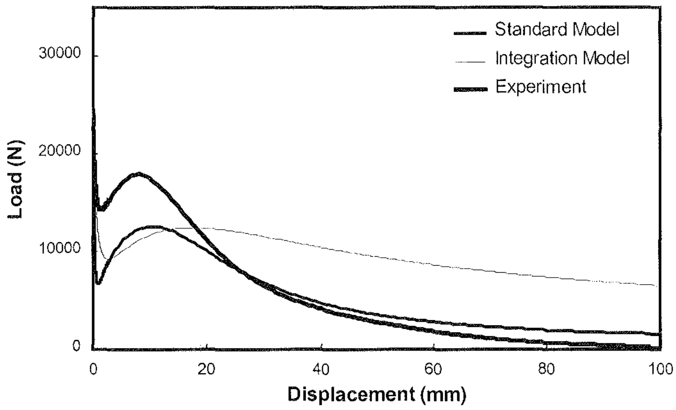

Figure 11. Load-displacement curves for Set 2 derived from experiments and Yield Line analysis.

4 DISCUSSION

On inspection of the results it is apparent that the numerical estimate of the load to cause first crack of the panels is always greater than that found experimentally. However, in the immediate post-crack range, the numerical estimates of residual load capacity were lower than the experimental result. It is also apparent that the integration model results in a higher estimate of post-crack capacity than the standard model, especially at large deflections. There are a number of possible reasons for this.

Firstly, experimental factors may have caused differences in material behaviour between the beams and panels. While the specimens examined in this investigation were all cured under the same conditions, the panels were tested in a surface dry state and the beams were tested in a surface saturated state. Bernard and Clements (2000) have shown that panels tested in a surface dry state exhibit a 16 per cent reduction in the load to cause first crack compared to panels tested in a surface saturated state. In the present investigation, the numerical estimates of the load to cause first crack in the panels were 14 per cent greater on average than the experimental results for the panels. Furthermore, the beams were cut on all faces, but the panels had a cast tensile face and a trowelled upper face. The condition of the tensile and compression faces therefore differed between the two types of specimen.

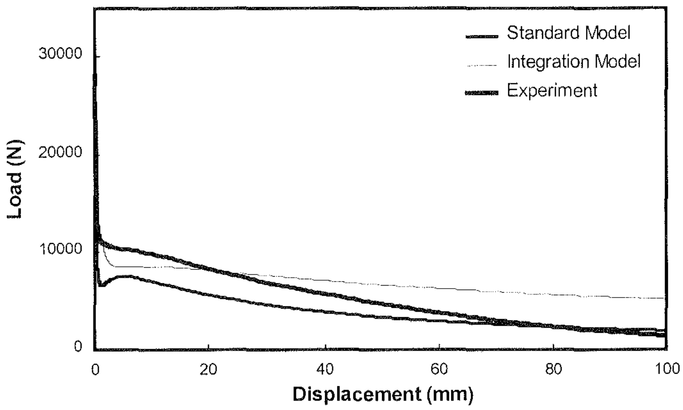

Figure 12. Load-displacement curves for Set 3 derived from experiments and Yield Line analysis.

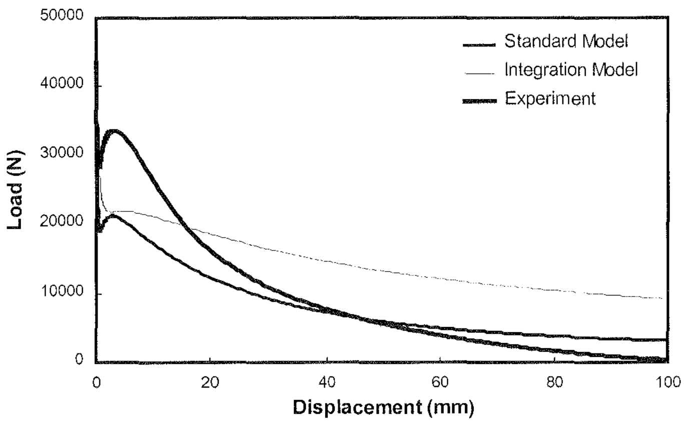

Figure 13. Load-displacement curves for Set 4 derived from experiments and Yield Line analysis.

The difference between the numerical and experimental estimates of residual load capacity in the immediate post-crack range may have arisen out of inherent problems with beam testing. Beams are known to exhibit unstable behaviour immediately after cracking if residual load capacity is low. All the present beam tests were undertaken in displacement control and several of the mixes exhibited very low residual load capacity immediately after cracking which make them prone to instability. The consequences of unstable post-crack behaviour have been widely debated (Mindess 1995), but the present results suggest that unstable beam behaviour may under-estimate capacity immediately after cracking.

The discrepancies between the experimental and numerical results may also be due to shortcomings in the numerical analyses. The yield lines were assumed to be symmetrically arranged, but in the laboratory panel tests the angles between each yield line were close to but not equal to 120°. As the discrepancy in magnitude between the three angles is increased, the numerical analysis predicts greater load resistance both at first crack and in the post-crack range.

The numerical estimates of residual load capacity at high levels of deformation in the panels were also greater than found in the experiments, especially when the integration model was used to calculate internal energy. The most likely explanation for this is that the beam tests upon which the numerical results were based did not experience tensile axial loads equivalent to the membrane stresses suffered by the panels at large deflections. The uncracked parts of each panel gradually separated at the centre as the deflection was increased, hence the moment resistance offered near the centre would have been lower than exhibited by simply supported beams at similar crack rotation angles. This is a phenomenon that is very difficult to incorporate into a yield line analysis because each yield line is assumed to experience a constant moment of resistance along its length.

Perhaps the most surprising result of the numerical analyses is that the standard model of internal energy calculation produced better overall estimates of post-crack performance than the integration model, despite not being rationally based. It appears that the errors in internal energy calculation inherent in this approach were cancelled out by neglect of the effect of axial tension across cracks.

5 CONCLUSION

A theoretical relationship between the behaviour of Round Determinate panels and Centrally Loaded beams made of FRS was developed on the basis of Yield Line theory. This was validated using experimental data obtained from a large number of tests on FRS specimens incorporating different fibre types and dosages. The theoretical analysis was found to predict behaviour with reasonable accuracy, but agreement was limited by differences between the methods of preparing and testing the beams and panels.

The results of this investigation have indicated that Yield Line theory is capable of modelling post-crack behaviour in strain softening FRS, but the accuracy of the prediction depends on the method used to calculate equilibrium within the failure mechanism. There is also a requirement to develop procedures that account for membrane tension across yield lines as this appears to exert a significant influence on behaviour.

6 ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of the following organisations and individuals in this investigation: CSR Readymix Concrete, through their representative Dr. Dak Baweja, for providing concrete; Jetcrete Australia P/L, through their representative Matthew Hicks, for assistance in producing specimens, and Synthetic Industries for support in funding the investigation. The respective fibre suppliers are also thanked for donations of fibres.

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ICCMC/IBST 2001 International Conference on Advanced Technologies in Design, Construction and Maintenance of Concrete Structures

MONTE CARLO ANALYSIS FOR CRACK MODELLING IN FIBRE REINFORCED SHOTCRETE PANELS

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ABSTRACT: *The ultimate load capacity of elastic-plastic structures such as conventionally reinforced concrete slabs has been shown to be modelled relatively well using Yield Line theory (YLT). Several types of Fibre Reinforced Shotcrete (FRS) exhibiting post-crack strain softening have therefore been studied using YLT in an attempt to predict the load deflection response of Round Determinate Panels (RDP). This paper describes a Monte Carlo method of incorporating empirically derived probabilistic information about crack patterns in a RDP to obtain the post-crack load-deformation response based on moment-crack rotation relationships developed from tests on beams made of the same material.*

KEYWORDS: *Yield Line Theory (YLT), Yield Line Analysis (YLA), Fibre Reinforced Concrete (FRC) and Shotcrete (FRS), Round Determinate Panel (RDP), Monte Carlo Simulation (MCS), Probabilistic Distribution Function (PDF).*

1. INTRODUCTION

Steel Fibre Reinforced Concrete and Shotcrete has increasingly been used in applications such as tunnel linings and industrial floors where ease of construction places it at an advantage relative to conventionally reinforced concrete. Based on test data gathered for Fibre Reinforced Concrete (FRC) and Shotcrete (FRS), many researchers have attempted to develop models for the post-crack behaviour of FRC and FRS. One test, the Round Determinate Panel (RDP) test [5] has been found to be particularly suitable for the assessment of such post-crack performance in FRC and FRS. This test has overcome several shortcomings and offered substantial experimental advantages compared to the earlier EFNARC panel test [1]. The advantages include insensitivity to specimen flatness, insensitivity to diameter, and a more consistent mode of failure. Performance sensitivity to thickness has been overcome through the development of thickness correction factors [11]. Peak load carrying capacity and total energy absorption are also generally lower than for alternative modes of specimen support, providing conservative estimates of panel performance [6]. The procedure involves the application of a central point load to a 75×800 mm diameter round panel that is supported on three symmetrically arranged pivoting points.

2. OBJECTIVE

The aim of this investigation is to derive a probabilistic distribution function (PDF) for the crack pattern in a RDP upon failure based on the data from a series of laboratory experiments. This function is then used in the development and implementation of a Monte Carlo Simulation (MCS) probabilistic analysis for the modelling of FRS in order to predict the load-deflection response of a RDP based on moment-crack rotation relationships developed from tests on beams made of the same material.

3. EXPERIMENTAL PROGRAM

The experimental data for the determination of the PDF for the crack patterns was obtained from several research programs. The experimental data describing the behaviour of FRS beams and RDP's for the MCS analyses included four sets of specimens reinforced with seven different types of fibre (Bernard et al 2000). Details of the mix design and fibres used for each set are given in Tables 1 and 2. Each set consisted of 20 beams and 20 panels in order to develop very reliable estimates of the characteristic behaviour.

Table 1. Mix design for FRC, all quantities in kg/m^3 unless otherwise indicated.

Ingredient	Sets 1-3	Set 4
Coarse agg. (5/7 mm)	640	640
Coarse sand (5 mm)	620	560
Fine sand (2 mm)	420	380
Cement (ASTM Type 1)	360	380
Fly ash	-	40
Silica Fume	40	40
Water reducer	1900 mL	1900 mL
Slump	65 mm	65 mm

Table 2. Fibre dosages (and source) used for each specimen set.

Set	Fibre type	Dosage (kg/m^3)
1	Novotex 0730 (Synthetic Ind.)	34
	256 EE (BHP Fibresteel)	27
2	50 mm HPP (Synthetic Ind.)	12
3	52 mm polyolefin (Dalhousie)	7.5
4	Dramix RC65/35 (Bekaert)	20
	Dramix BP80/35 (Bekaert)	15
	50 mm HPP (Synthetic Ind.)	3

Beam testing: Moment-crack rotation relationships were measured using the Centrally Loaded Beam test, developed by Bernard [7]. This test involves the imposition of a central point load on a saw-cut FRS beam and measurement of rotation at the crack as a function of the applied moment. In contrast to data produced using conventional third-point loaded beams [4,1] these tests result in data of direct structural relevance. The size of the specimen used is the same as that used in the EFNARC third-point beam test (75×125×550 mm, on a 450 mm span). The method used to measure and calculate the relationship between moment and crack rotation in these specimens is described in detail in Bernard et al. (2000).

Panel testing: In the RDP test, a central point load is imposed on a specimen measuring 75×800 mm diameter, supported on three radial points located on a 750 mm picth circle diameter. Specimens tested by Bernard et al (2000) were placed in a test fixture located within an Instron 8506 servo-hydraulic test machine and loaded in displacement-control up to 100mm total central deflection.

The data from each set of 20 specimens consisted of load and displacement results. This was analyzed using a least-squares adjusted curve-fitting program to develop a numerical approximation of the mean load-displacement curve for each set of nominally identical specimens.

4. YIELD LINE THEORY AND NUMERICAL ANALYSIS

Yield Line Theory [2] undertaking the present analysis is described detail in [3]. A detailed Yield Line Analysis (YLA) for RDP's is shown in the Appendix.

The numerical analysis is also described detail in [4]. However, the process is repeated for three other crack locations. The structure and operation of the software program for each iteration are described in Figure 1.

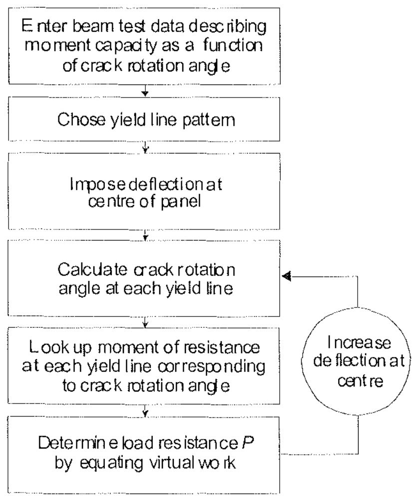

Figure 1. Structure and operatin of numerical code for the estimate of post-crack behaviour using YLA.

5. DISTRIBUTION FUNCTION OF MIDPOINT ANGLE

A RDP specimen fails in flexure with three primary radial cracks. The origin of the crack is assumed to be located immediately below the centre of loading. The deviation of the crack from the midpoint line between two pivots is called the midpoint angle (see Figure 2) which always varies from 0 to 60^0 on either side of the midpoint. This variation results in a variation in the relationship between load capacity and deflection.

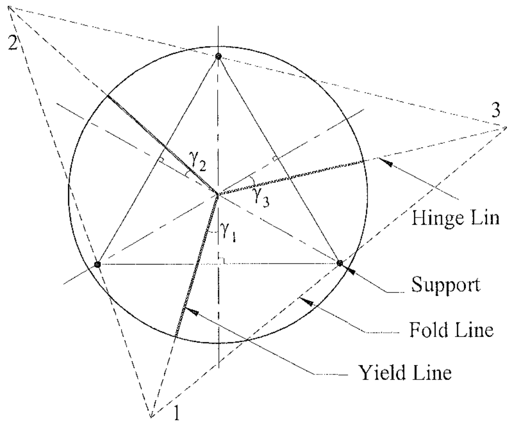

Figure 2. Midpoint angles in typical failure pattern for a RDP.

Each of the cracks has a corresponding value of midpoint angle. Since there are normally three cracks, each panel therefore gives rise to three midpoint angles. Midpoint angles have been measured in about 500 panel tests, thereby giving rise to 1500 values of midpoint angle based on test results reported by Bernard, Bernard and Pircher in [11], Bernard in [8] and Bernard et al. (2000). An analysis has been carried out using this data set of midpoint angles to determine a PDF relating angle and frequency. The most suitable distribution functions were deduced on the basis of the Chi-square test (χ^2) [12] for goodness-of-fit. The Chi-square statistic is:

$$\chi^2 = \sum_{i=1}^{n} \frac{(N_j - np_j)^2}{np_j}$$

where n = number of data points,

N_j = number of X_i's in the jth interval $[a_{j-1}, a_j]$ for $j=1,2,..,k$.

$p_j = \int_{a_{j-1}}^{a_j} \hat{f}(x)dx$ where $\hat{f}$ is the density function for the continuous case.

The rank of some probabilistic distribution functions [12] for the present midpoint data is presented in Tables 3. Based on these results, it appears that the Weibull distribution is the best fit to the present data.

Function	χ^2
1.Weibull	1.462038
2.Exponential	1.548877
3.Erlang	1.587123
4.Lognorm	1.769982
5.Lognorm2	1.769982
6.Gamma	3.303935
7.Triangle	3.759661

Table 3. Function rank by Chi-Square Test

The Weibull distribution function is given by:

$$F(x) = 1 - e^{-\left(\frac{x}{\beta}\right)^{\alpha}} \quad if\, x>0 \text{ and } \quad F(x) = 0 \quad if\, x \leq 0$$

where: $\alpha = 0.978055$ and $\beta = 12.033792$ (from 500 panels)

The mean = $(\beta/\alpha)\,\Gamma\,(1/\alpha) = 11.850451$ where: $\Gamma(\varphi)$ is the Gamma Function [12].

$$\text{The variance} = \frac{\beta^2}{\alpha}\left[2\Gamma\left(\frac{2}{\alpha}\right) - \frac{1}{\alpha}\Gamma\left(\frac{1}{\alpha}\right)^2\right] = 154.355063$$

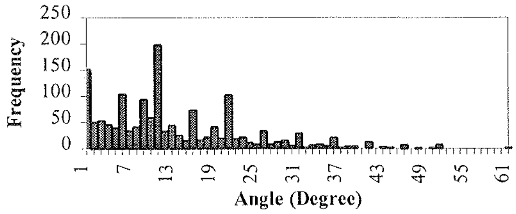

Figure 3. The cumulative frequency distribution of the input data.

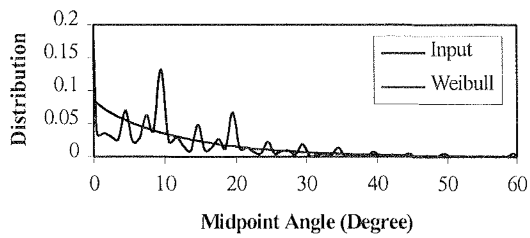

Figure 4. Comparison of Input Density Distribution and Weibull function.

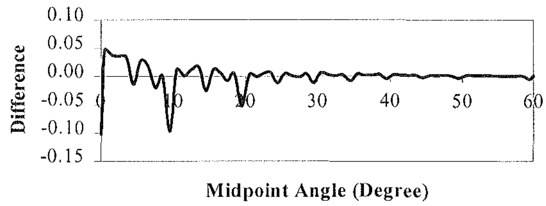

Figure 5. Difference between Input Distribution and Weibull function.

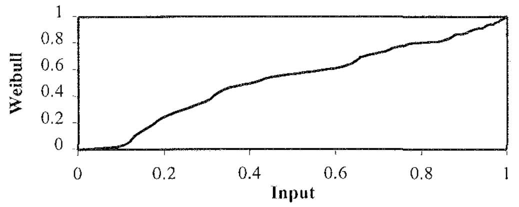

Figure 6. Probabilistic - Probabilistic Comparison between Input and Weibull function.

Figure 4 displays the two sets of data, these being the input distribution and the distribution created by the best-fit analysis (Weibull). The difference between the input and the fitted distribution is shown in Figure 5. This graph displays the absolute error between the input and Weibull distribution. This error is defined as the difference between the input and result probability. Comparing the magnitude of the error to the magnitude of the result, we can see that the result deviates significantly from the input for the range 0 to 30 degrees and a little bit for the range 30 to 60 degrees. The Probabilistic-Probabilistic (P-P) graph in Figure 6 plots the distribution of the input data versus the distribution of the result. If the fit is good, the plot will be nearly linear. These graphs show that the Weibull distribution agrees relatively well with the input data.

6. MONTE CARLO SIMULATION :

Monte Carlo sampling refers to the technique of using random or pseudo-random numbers to sample from a probabilistic distribution. In the cumulative distribution, each Monte Carlo sample uses a new random number between 0 and 1. In a MCS, the algorithm firstly generates a random variable for each of the independent variables according to a specified PDF. A single outcome from the analysis is subsequently obtained. This process is then repeated a large number of times.

There are many techniques for generating random variables, and the particular algorithm used must, of course, depend on the distribution from which we wish to generate. The formula of the Weibull distribution function is:

$$F(x) = 1 - e^{-\left(\frac{x}{\beta}\right)^{\alpha}} \quad (if\, x>0) \qquad \text{and} \qquad F(x) = 0 \quad (if\, x \leq 0)$$

So to find F^{1}, we set $u=F(x)$ and solve for x to obtain: $F^{1}(u) = \beta[-ln(1-u)]^{1/\alpha}$

Thus, to generate the desired random variable we first generate $U \sim U(0,1)$ and then let:

$X = \; = \beta\,(-lnU)^{1/\alpha}$ where U can be $1\text{-}U$, since $1\text{-}U$ has the same $U(0,1)$ distribution.

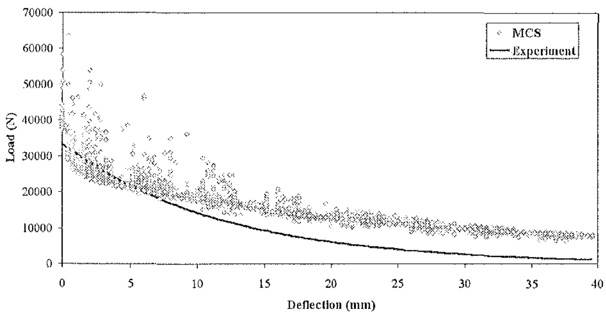

Figure 7. Comparison between Load-Deflection curves for RDP's from experiment and 25000 data points from 5000 MCS analyses for Set 1 (Table 2).

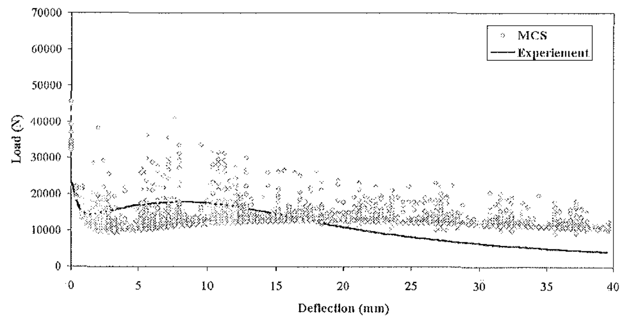

Figure 8. Comparison between Load-Deflection curves for RDP's from experiment and 25000 data points from 5000 MCS analyses for set 2 (Table 2).

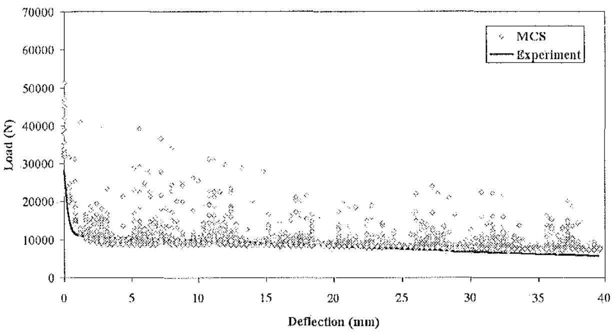

Figure 9. Comparison between Load-Deflection curves for RDP's from experiment and 25000 data points from 5000 MCS analyses for Set 3 (Table 2).

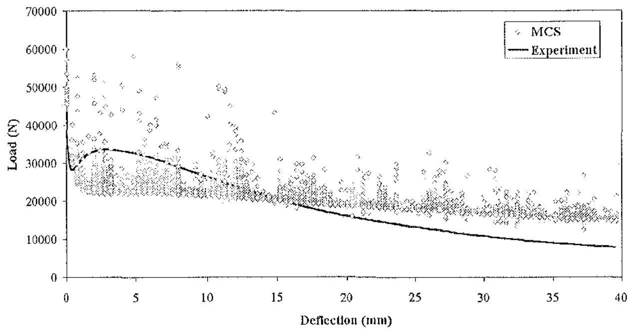

Figure 10. Comparison between Load-Deflection curves for RDP's from experiment and 25000 data points from 5000 MCS analyses for Set 4 (Table 2).

A program based on YLA integrated with MCS has been developed to calculate a theoretical load-deflection curve for a RDP made with FRS based on the results from a moment-rotation beam test using the same mix. The expressions that resulted from curve-fitting the beam test data in section 3 were used as input to the YLA combined with MCS analyses to produce estimates of post-crack behaviour in the panels. These have been compared to the experimental results from the panel tests in Figures 7 to 10.

The crack can deviate from two sides of the midpoint line between two pivots. This causes the midpoint angles assumed to be negative or positive. Therefore, the program randomly generates the sign of the midpoint angles.

The numerical analyses were performed in a step-wise manner to change the moment resistance of the crack as the rotation angles increase. The virtual work theorem was then used to solve for the load resistance using an integration model [3] to calculate internal energy absorption. By this method, the 3 crack rotations can be incorporated into a MCS analysis to derive the relation between load and deflection. In the production of load-deflection curves, Microsoft Excel has been adopted, but due to a limitation with this program only 255 curves can be obtained on a single set of axes. However, more than 50000 data points can be drawn on the same graph. In each of the iterations, the program randomly picks 5 data points on each load-deflection curve. Therefore, in 5000 iterations, we can put 25000 points on the graph. The data points line up in vertical rows parallel to the load axis because we used an increment of deflection in the program to calculate the capacity. The program saves 5 data points from each iteration and many of these data points have the same deflection.

It is evident in Figure 7 to 10 that the theoretical load to cause first crack is always greater than the experimental result. This is due to the fact that the panels were tested in a dry state, while the beams were tested wet. It has been shown that a dry surface can result in a drop in load capacity compared to wet panels [9]. The residual load capacity is lower than that found in experiments in the immediate post-crack area. The fact that compressive arch action is not accounted for in the analyses probably explains the discrepancy in the immediate post-crack range (up to about 5 mm). Furthermore, the residual capacity was greater than that in the experiments at high deflections because the numerical procedure does not include the membrane actions in the panel at large deflections. The difference between theory and experiment has also been examined by Tran et al [3].

Despite the influence of other factors, the most important reason for the discrepancies between the experimental and numerical results is the variation in the position of the yield lines, which is represented by the magnitude of the midpoint angles. In this paper, the variation in the midpoint angles is incorporated into a MCS analysis in order that estimates of load-deflection output for the panels can be made. The results displayed in Figures 7 to 10 indicate that a distribution of data points exists around the experimental curves between a deflection of 0 and 20 mm. This is not evident in the analyses described in [3] in which the 3 yield lines are constrained to a symmetrical arrangement. This improvement has indicated that YLA combined with a PDF describing the characteristic crack pattern is capable of accounting for a significant part of the variation in post-cracked behaviour in FRS panels.

7. CONCLUSION

By considering the variation of position of yield lines in RDP's, a YLA combined with MCS is developed to model post-crack behaviour in strain softening FRS. From the studies of RDP specimens in this investigation, the following conclusions can be made:

- Weibull probabilistic density functions provide a reasonable model for the crack positions that occur in RDP's and are suitable for incorporation into a MCS method.
- YLA incorporating a MCS analysis can provide a good prediction of post-cracking behaviour in FRS RDP's but the accuracy still depends on calculating equilibrium within the failure mechanism.
- The accuracy of the predictions is limited by differences in the methods of preparing, cutting and testing beams and panels.

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APPENDIX

Relation of Load Capacity and Deflection:

The external energy: $U_{ext} = P\delta$

The internal energy:

$$U_{\text{int}} = \int m_1(\theta_1)Rd\theta_1 + \int m_2(\theta_2)Rd\theta_2 + \int m_3(\theta_3)Rd\theta_3$$

By the virtual work theorem, $U_{ext} = U_{int}$,

Hence:

$$P = \frac{1}{\delta}\left(\int m_1(\theta_1)Rd\theta_1 + \int m_2(\theta_2)Rd\theta_2 + \int m_3(\theta_3)Rd\theta_3\right)$$

Where: R : the radius of the panel.

m_1, m_2 and m_3 : the moments of resistance per unit length along the three cracks.

θ_1, θ_2, and θ_3 : the angles of rotation between the sets of planes.

Otherwise,

$\theta_1 = \text{atan}(A\delta) + \text{atan}(B\delta)$

$\theta_2 = \text{atan}(C\delta) + \text{atan}(D\delta)$

$\theta_3 = \text{atan}(E\delta) + \text{atan}(F\delta)$

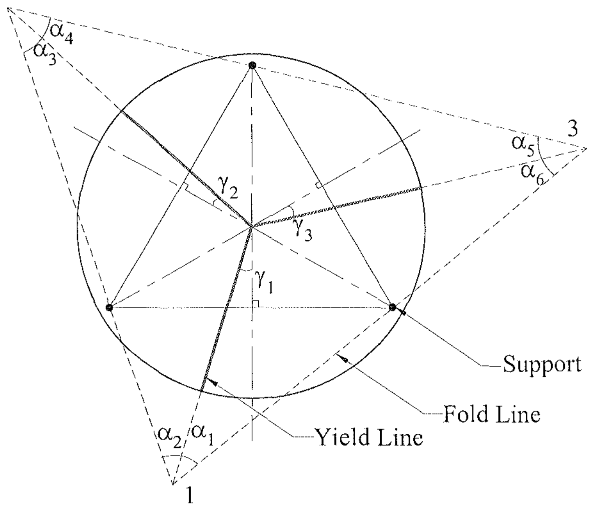

Figure A1. General pattern of three radial yield at unequal midpoint angles γ_1, γ_2 and γ_3; and the corner angles α_1, α_2, α_3, α_4, α_5, and α_6

Where:
$$A = \frac{\sin(\alpha_2 + \frac{\pi}{3} - \gamma_1) - \cos(\frac{\pi}{3} - \gamma_1).\sin\alpha_2}{r.\sin(\frac{\pi}{3} - \gamma_1).\sin(\alpha_2 + \frac{\pi}{3} - \gamma_1)} \qquad B = \frac{\sin(\alpha_2 + \frac{\pi}{3} - \gamma_1) - \cos(\frac{\pi}{3} + \gamma_1).\sin\alpha_2}{r.\sin(\frac{\pi}{3} + \gamma_1).\sin(\alpha_2 + \frac{\pi}{3} - \gamma_1)}$$

$$C = \frac{\sin(\alpha_4 + \frac{\pi}{3} - \gamma_2) - \cos(\frac{\pi}{3} - \gamma_2).\sin\alpha_4}{r.\sin(\frac{\pi}{3} - \gamma_2).\sin(\alpha_4 + \frac{\pi}{3} - \gamma_2)} \qquad D = \frac{\sin(\alpha_4 + \frac{\pi}{3} - \gamma_2) - \cos(\frac{\pi}{3} + \gamma_2).\sin\alpha_4}{r.\sin(\frac{\pi}{3} + \gamma_2).\sin(\alpha_4 + \frac{\pi}{3} - \gamma_2)}$$

$$E = \frac{\sin(\alpha_6 + \frac{\pi}{3} - \gamma_3) - \cos(\frac{\pi}{3} - \gamma_3).\sin\alpha_6}{r.\sin(\frac{\pi}{3} - \gamma_3).\sin(\alpha_6 + \frac{\pi}{3} - \gamma_3)} \qquad F = \frac{\sin(\alpha_6 + \frac{\pi}{3} - \gamma_3) - \cos(\frac{\pi}{3} + \gamma_3).\sin\alpha_6}{r.\sin(\frac{\pi}{3} + \gamma_3).\sin(\alpha_6 + \frac{\pi}{3} - \gamma_3)}$$

The corner angles α_2, α_4, and α_6 are be found by:

$X_1u_1^2 + Y_1u_1 + Z_1 = 0$; $X_2u_2^2 + Y_2u_2 + Z_2 = 0$; $X_3u_3^2 + Y_3u_3 + Z_3 = 0$

Where: $u_1 = \tan\alpha_2$, $u_2 = \tan\alpha_4$, $u_3 = \tan\alpha_6$

$$X_1 = \frac{\left[(a_{13}\sin\gamma_{21} - a_{12}\cos\gamma_{21})(\cos\gamma_1^- \cos\gamma_{13} - \sqrt{3}\sin\gamma_1 \sin\gamma_{13}) + b_{12}\cos\gamma_3^+(\sqrt{3}\sin\gamma_1\cos\gamma_{13} + \cos\gamma_1^- \sin\gamma_{13})\right]}{\cos\gamma_{13}\cos\gamma_{21}\cos\gamma_{32}}$$

$$Y_1 = \frac{\begin{bmatrix}(a_{12}\sin\gamma_{21} + a_{13}\cos\gamma_{21})(\cos\gamma_1^- \cos\gamma_{13} - \sqrt{3}\sin\gamma_1\sin\gamma_{13}) - \cos\gamma_1^+ \sin\gamma_{13}(a_{13}\sin\gamma_{21} - a_{12}\cos\gamma_{21}) \\ + \cos\gamma_3^+\left[b_{12}\cos\gamma_1^+\cos\gamma_{13} + b_{13}(\sqrt{3}\sin\gamma_1\cos\gamma_{13} + \cos\gamma_1^- \sin\gamma_{13})\right]\end{bmatrix}}{\cos\gamma_{13}\cos\gamma_{21}\cos\gamma_{32}}$$

$$Z_1 = \frac{\left[b_{13}\cos\gamma_1^+\cos\gamma_3^+\cos\gamma_{13} - \cos\gamma_1^+\sin\gamma_{13}(a_{12}\sin_{21} + a_{13}\cos\gamma_{21})\right]}{\cos\gamma_{13}\cos\gamma_{21}\cos\gamma_{32}}$$

$$X_2 = \frac{\left[(a_{23}\sin\gamma_{32} - a_{22}\cos\gamma_{32})(\cos\gamma_2^- \cos\gamma_{21} - \sqrt{3}\sin\gamma_2\sin\gamma_{21}) + b_{22}\cos\gamma_1^+(\sqrt{3}\sin\gamma_2\cos\gamma_{21} + \cos\gamma_2^- \sin\gamma_{21})\right]}{\cos\gamma_{21}\cos\gamma_{32}\cos\gamma_{13}}$$

$$Y_2 = \frac{\begin{bmatrix}(a_{22}\sin\gamma_{32} + a_{23}\cos\gamma_{32})(\cos\gamma_2^- \cos\gamma_{21} - \sqrt{3}\sin\gamma_2\sin\gamma_{21}) - \cos\gamma_2^+ \sin\gamma_{21}(a_{23}\sin\gamma_{32} - a_{22}\cos\gamma_{32}) \\ + \cos\gamma_1^+\left[b_{22}\cos_2^+\cos\gamma_{21} + b_{23}(\sqrt{3}\sin\gamma_2\cos\gamma_{21} + \cos\gamma_2^- \sin\gamma_{21})\right]\end{bmatrix}}{\cos\gamma_{21}\cos\gamma_{32}\cos\gamma_{13}}$$

$$Z_2 = \frac{\left[b_{23}\cos\gamma_1^+\cos\gamma_2^+\cos\gamma_{21} - \cos\gamma_2^+\sin\gamma_{21}(a_{22}\sin_{32} + a_{23}\cos\gamma_{32})\right]}{\cos\gamma_{21}\cos\gamma_{32}\cos\gamma_{13}}$$

$$X_3 = \frac{\left[(a_{33}\sin\gamma_{13} - a_{32}\cos\gamma_{13})(\cos\gamma_3^- \cos\gamma_{32} - \sqrt{3}\sin\gamma_3\sin\gamma_{32}) + b_{32}\cos\gamma_2^+(\sqrt{3}\sin\gamma_3\cos\gamma_{32} + \cos\gamma_3^-\sin\gamma_{32})\right]}{\cos\gamma_{13}\cos\gamma_{32}\cos\gamma_{21}}$$

$$Y_3 = \frac{\left[\begin{array}{l}(a_{32}\sin\gamma_{13} + a_{33}\cos\gamma_{13})(\cos\gamma_3^- \cos\gamma_{32} - \sqrt{3}\sin\gamma_3\sin\gamma_{32}) - \cos\gamma_3^+\sin\gamma_{32}(a_{33}\sin\gamma_{13} - a_{32}\cos\gamma_{13}) \\ + \cos\gamma_2^+\left[b_{32}\cos\gamma_3^+\cos\gamma_{32} + b_{33}(\sqrt{3}\sin\gamma_3\cos\gamma_{32} + \cos\gamma_3^-\sin\gamma_{32})\right]\end{array}\right]}{\cos\gamma_{13}\cos\gamma_{32}\cos\gamma_{21}}$$

$$Z_3 = \frac{\left[b_{33}\cos\gamma_2^+\cos\gamma_3^+\cos\gamma_{32} - \cos\gamma_3^+\sin\gamma_{32}(a_{32}\sin_{13} + a_{33}\cos\gamma_{13})\right]}{\cos\gamma_{13}\cos\gamma_{32}\cos\gamma_{21}}$$

$$a_{12} = \cos\gamma_2^+(\sqrt{3}\sin\gamma_3\cos\gamma_{32} + \cos\gamma_3^-\sin\gamma_{32}) - \sqrt{3}\sin\gamma_2(\cos\gamma_3^-\cos\gamma_{32} - \sqrt{3}\sin\gamma_3\sin\gamma_{32})$$

$$a_{13} = \cos\gamma_2^-(\cos\gamma_3^-\cos\gamma_{32} - \sqrt{3}\sin\gamma_3\sin\gamma_{32})$$

$$b_{12} = \cos\gamma_2^+\cos\gamma_{32}\cos\gamma_{21} + \sqrt{3}\sin\gamma_{32}\sin\gamma_2\cos\gamma_{21} + \cos\gamma_2^-\sin\gamma_{32}\sin\gamma_{21}$$

$$b_{13} = \sin\gamma_{32}\cos\gamma_2^-\cos\gamma_{21} - \sin\gamma_{21}(\cos\gamma_2^+\cos\gamma_{32} + \sqrt{3}\sin\gamma_{32}\sin\gamma_2)$$

$$a_{22} = \cos\gamma_3^+(\sqrt{3}\sin\gamma_1\cos\gamma_{13} + \cos\gamma_1^-\sin\gamma_{13}) - \sqrt{3}\sin\gamma_3(\cos\gamma_1^-\cos\gamma_{13} - \sqrt{3}\sin\gamma_1\sin\gamma_{13})$$

$$a_{23} = \cos\gamma_3^-(\cos\gamma_1^-\cos\gamma_{13} - \sqrt{3}\sin\gamma_1\sin\gamma_{13})$$

$$b_{22} = \cos\gamma_3^+\cos\gamma_{13}\cos\gamma_{32} + \sqrt{3}\sin\gamma_{13}\sin\gamma_3\cos\gamma_{32} + \cos\gamma_3^-\sin\gamma_{13}\sin\gamma_{32}$$

$$b_{23} = \sin\gamma_{13}\cos\gamma_3^-\cos\gamma_{32} - \sin\gamma_{32}(\cos\gamma_3^+\cos\gamma_{13} + \sqrt{3}\sin\gamma_{13}\sin\gamma_3)$$

$$a_{32} = \cos\gamma_1^+(\sqrt{3}\sin\gamma_2\cos\gamma_{21} + \cos\gamma_2^-\sin\gamma_{21}) - \sqrt{3}\sin\gamma_1(\cos\gamma_2^-\cos\gamma_{21} - \sqrt{3}\sin\gamma_2\sin\gamma_{21})$$

$$a_{33} = \cos\gamma_1^-(\cos\gamma_2^-\cos\gamma_{21} - \sqrt{3}\sin\gamma_2\sin\gamma_{21})$$

$$b_{32} = \cos\gamma_1^+\cos\gamma_{21}\cos\gamma_{13} + \sqrt{3}\sin\gamma_{21}\sin\gamma_1\cos\gamma_{13} + \cos\gamma_1^-\sin\gamma_{21}\sin\gamma_{13}$$

$$b_{33} = \sin\gamma_{21}\cos\gamma_1^-\cos\gamma_{13} - \sin\gamma_{13}(\cos\gamma_1^+\cos\gamma_{21} + \sqrt{3}\sin\gamma_{21}\sin\gamma_1)$$

$\gamma_{32} = \pi/3 - \gamma_3 + \gamma_2$; $\gamma_{21} = \pi/3 - \gamma_2 + \gamma_1$; $\gamma_{13} = \pi/3 - \gamma_1 + \gamma_3$; $\gamma^+_1 = \pi/6 + \gamma_1$; $\gamma^+_2 = \pi/6 + \gamma_2$; $\gamma^+_3 = \pi/6 + \gamma_3$; $\gamma^-_1 = -\pi/6 + \gamma_1$; $\gamma^-_2 = -\pi/6 + \gamma_2$; $\gamma^-_3 = -\pi/6 + \gamma_3$;

Thus,

$$\alpha_2 = a\tan\left(\frac{-Y_1 + \sqrt{Y_1^2 - 4X_1Z_1}}{2X_1}\right); \quad \alpha_4 = a\tan\left(\frac{-Y_2 + \sqrt{Y_2^2 - 4X_2Z_2}}{2X_2}\right); \quad \alpha_6 = a\tan\left(\frac{-Y_3 + \sqrt{Y_3^2 - 4X_3Z_3}}{2X_3}\right)$$